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Daedalus: Design for a Starship

Observing the Autumn Galaxies

1983 Buyer's Guide to Telescopes

ICD# 08070 71574

The Indonesian Eclipse

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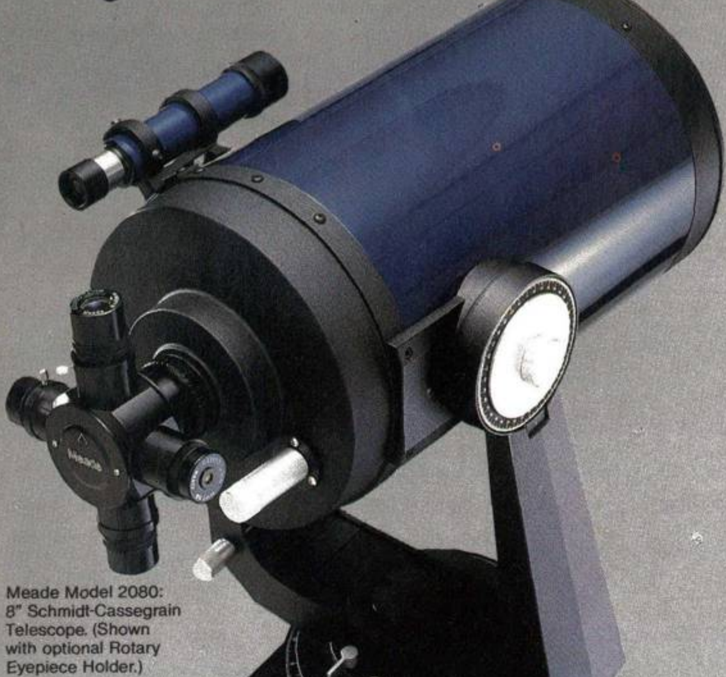

Meade Model 2080: 8" Schmidt-Cassegrain Telescope. (Shown with optional Rotary Eyepiece Holder.)

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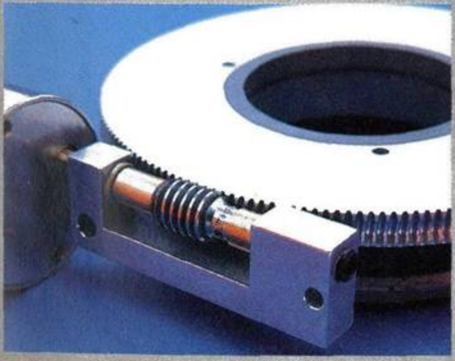

The standard worm-gear drive system of the Meade 8" Model 2080.

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Latitude scale of the Equatorial Wedge.

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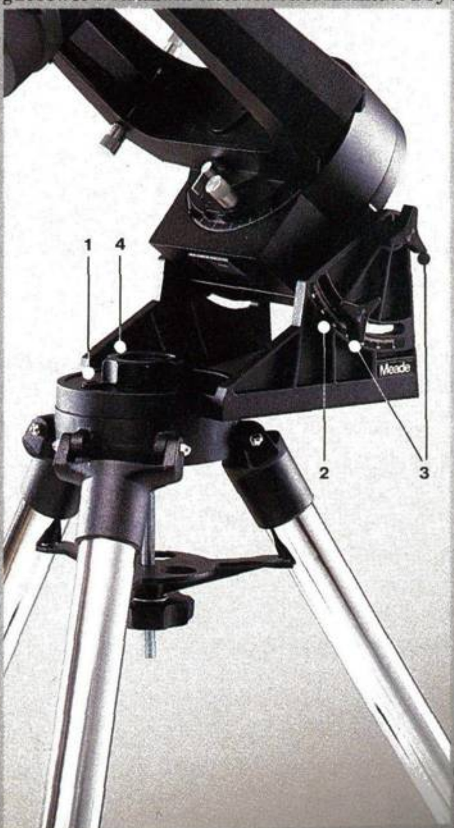

The Meade Equatorial Wedge/Field Tripod System.

(1) Bubble level; (2) Latitude scale; (3) No-Tool-Required adjustment knobs; (4) Wedge-to-Tripod lock knob, permitting 360° Wedge adjustments in azimuth.

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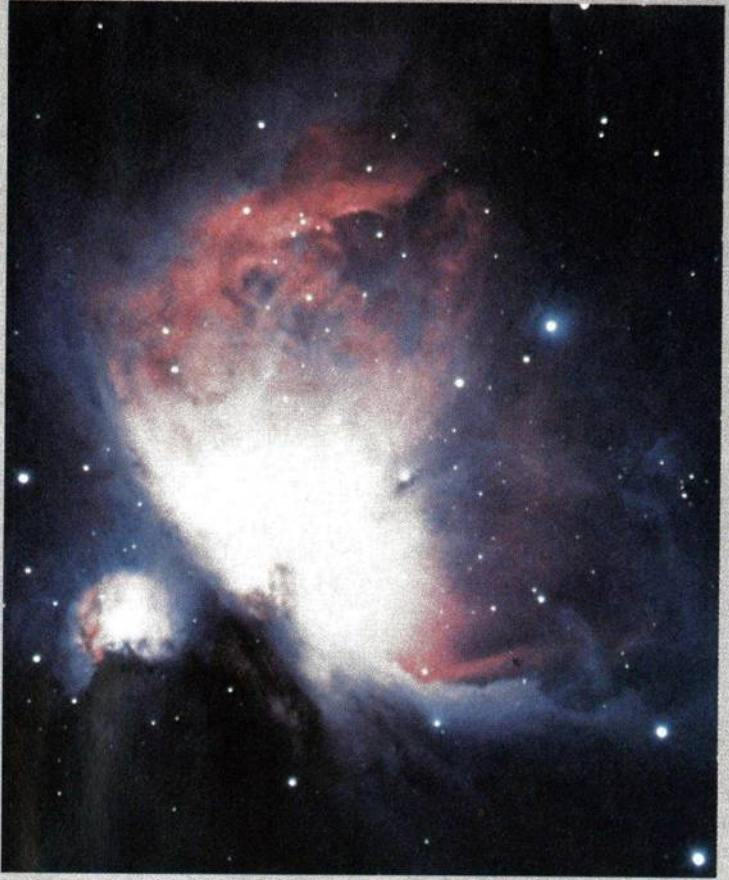

Great Nebula in Orion (M42). A 50-minute exposure on Ektachrome 400 through the Meade 8" Model 2080.

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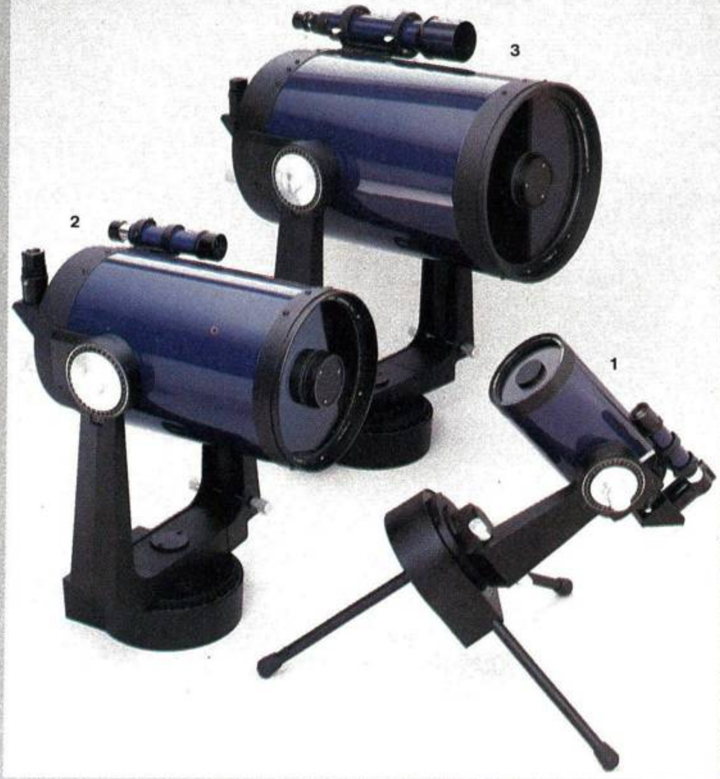

Meade Schmidt-Cassegrain Telescopes. (1) 4" Model 2044, with standard-equipment table tripod; (2) 8" Model 2080; (3) 10" Model 2120.

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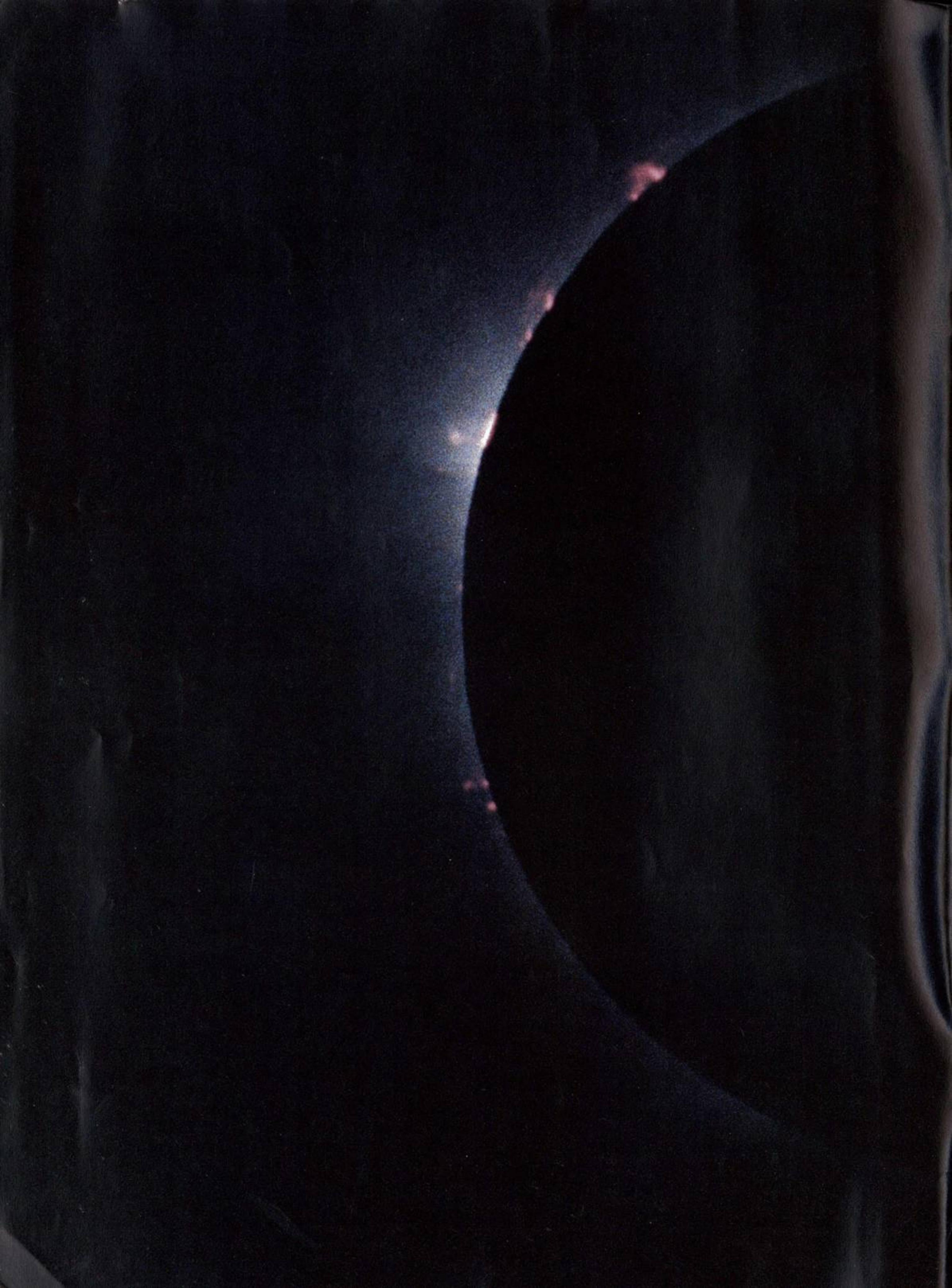

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Cover: Huguette Guertin photographed the June 11 solar eclipse from Salatiga in central Java on Kodachrome II film. That, however, was just the beginning. Because the innermost parts of the corona are hundreds of times brighter than the faint outer corona, many hours of careful darkroom work were required to produce a final print capturing the full range of brightness. These pages: About 10 seconds before third contact, delicate details of prominences and chromosphere came into view. Photo by Richard Berry.

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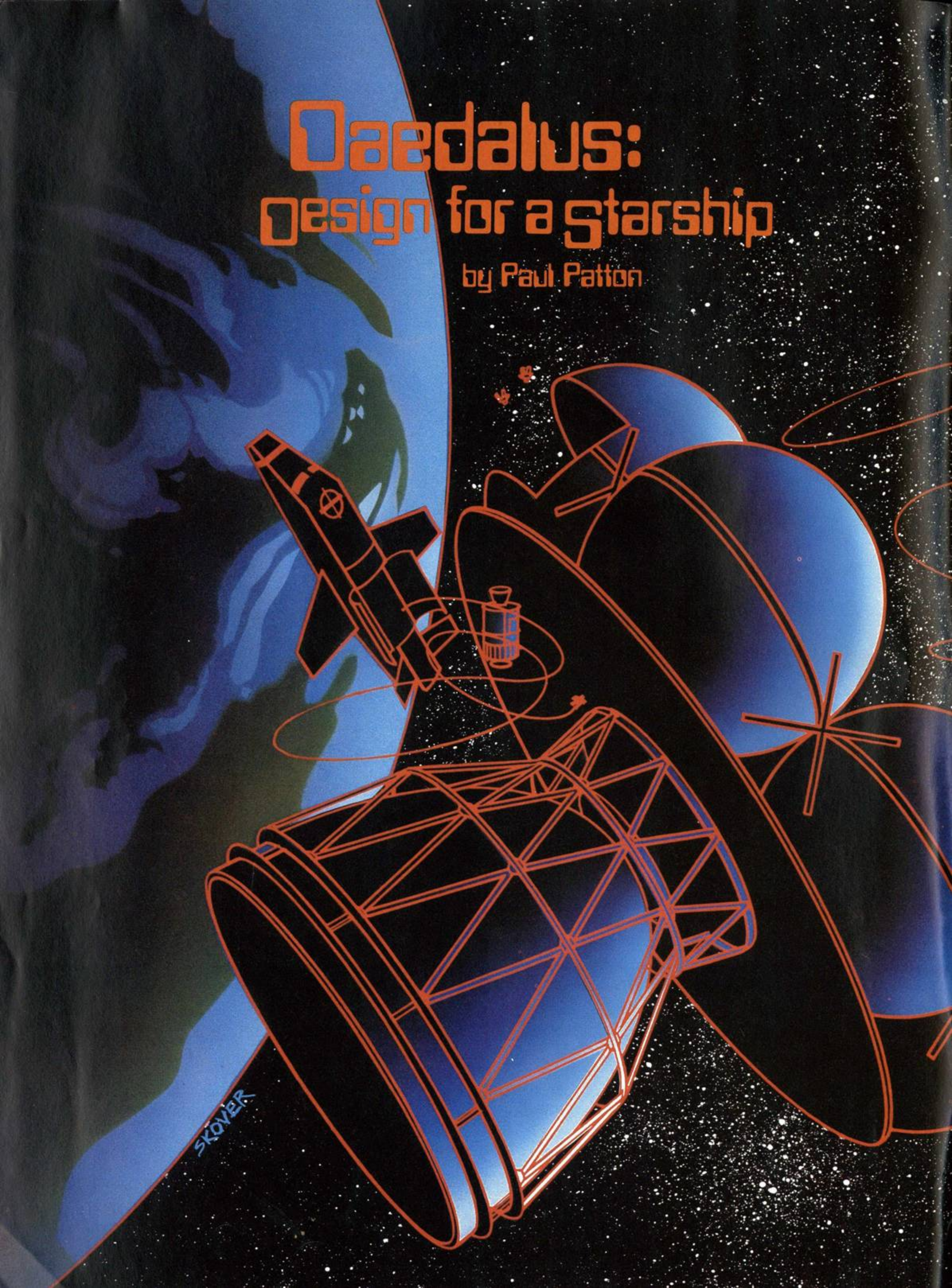
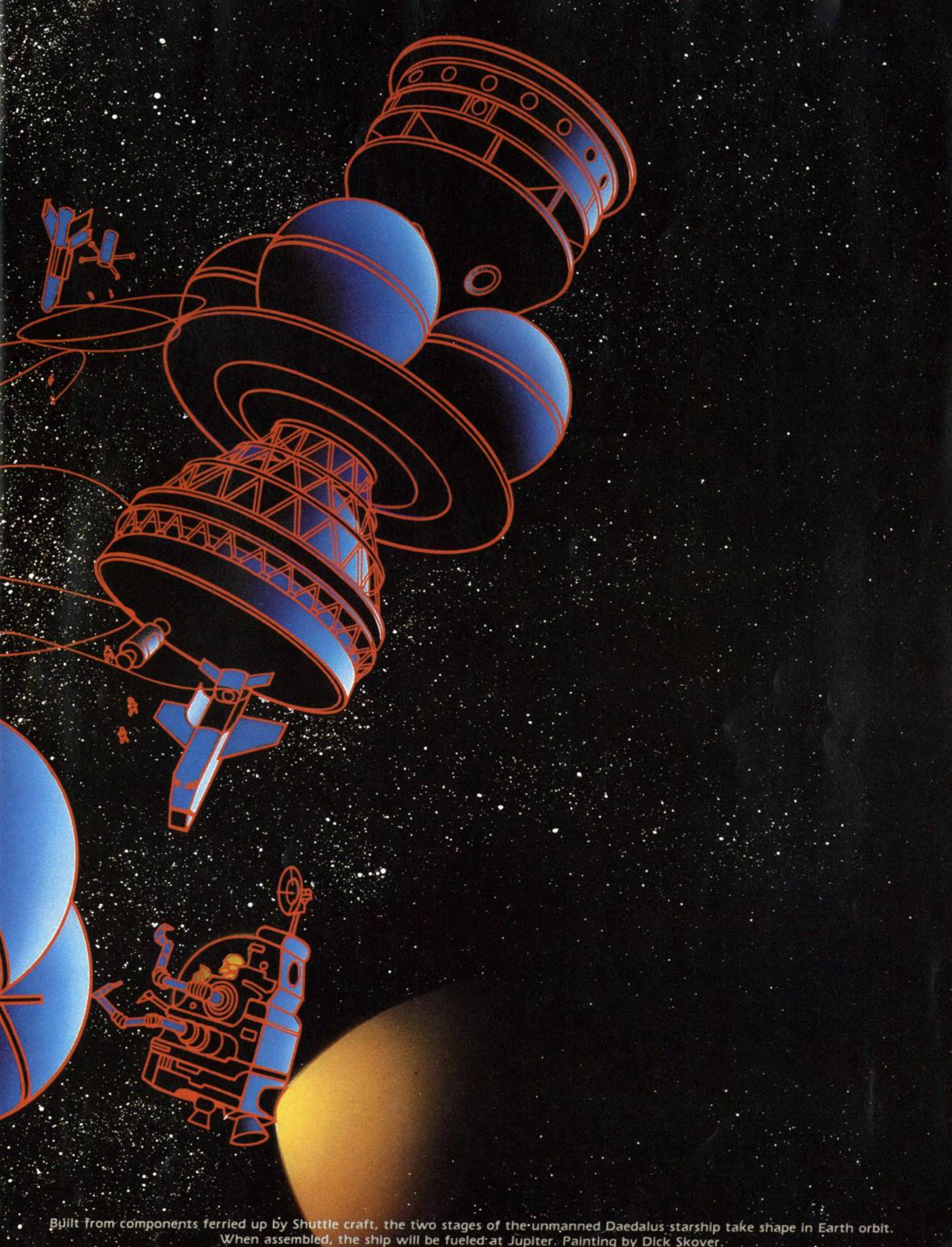
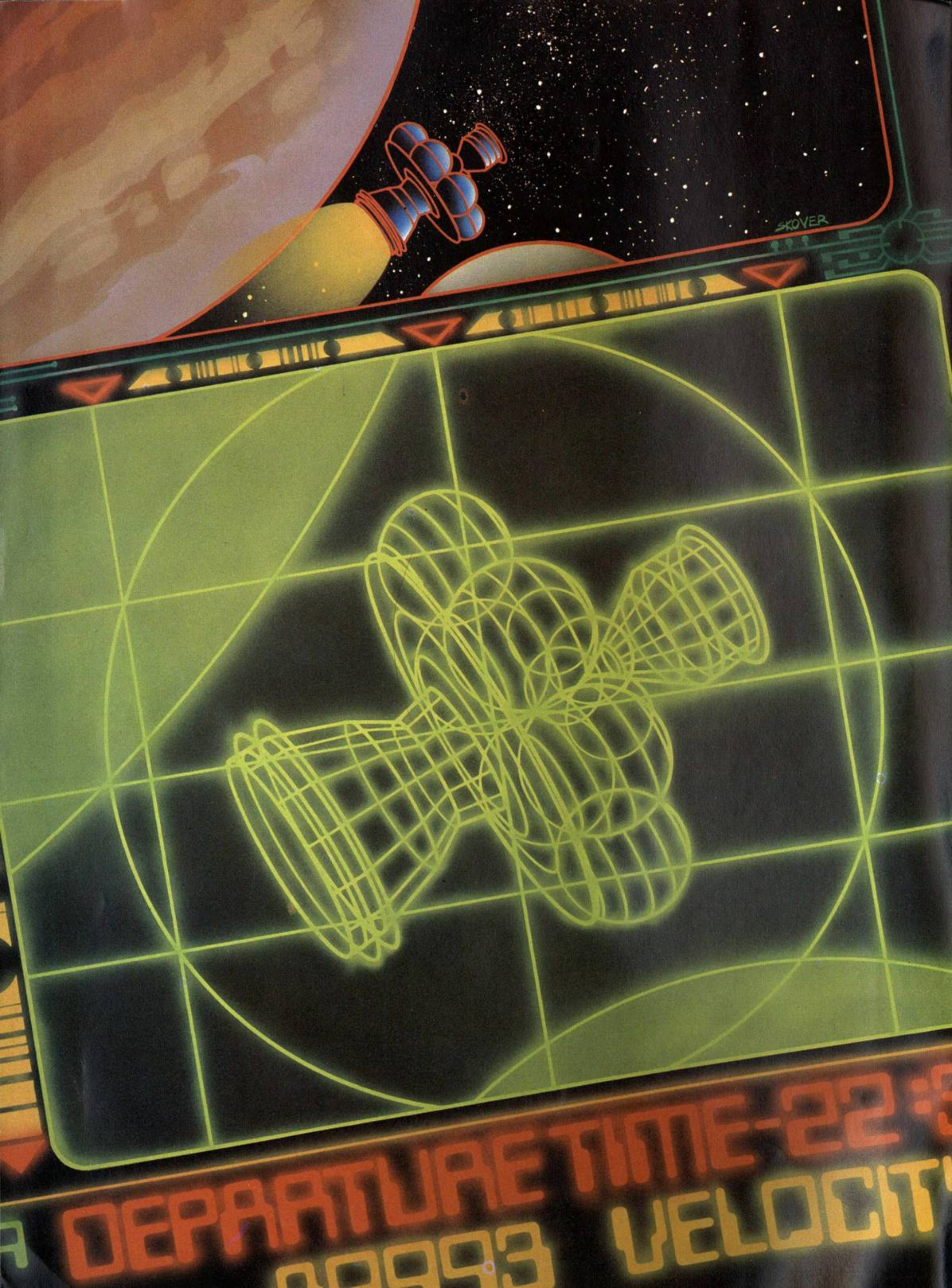
Daedalus: Design for a Starship

by Paul Patton





Built from components ferried up by Shuttle craft, the two stages of the unmanned Daedalus starship take shape in Earth orbit. When assembled, the ship will be fueled at Jupiter. Painting by Dick Skover.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Daedalus:
Design for a Starship

Over the last quarter century, space technology has opened up the solar system to direct exploration. Sophisticated robots from Earth have been hurled deep into interplanetary space, probing five of the Sun's nine major planets. These voyages have taught us more about our solar system than observers bound to the Earth could have ever hoped to learn; they have prepared the way for eventual manned interplanetary expeditions. Yet the solar system is only an infinitesimal speck in the vast swarm of several hundred billion stars that is our Galaxy. Peering across the void of interstellar space with powerful telescopes, we have learned that the stars are other suns. Many may possess their own retinues of planets — entire worlds about which we know absolutely nothing. Can we ever hope to send robot emissaries to explore these remote worlds?

In the opinion of a group of British scientists and engineers, the answer is yes. The scientists, working under the auspices of the British Interplanetary Society, took part in a five-year design study for such a starship, called Project Daedalus. They concluded that a robot starship to explore nearby stellar systems might be built by the middle of the 21st century.

The British Interplanetary Society, founded in 1933, is one of the world's oldest and most respected space organizations. The society has a long tradition of innovative studies into the future of spaceflight. One of the group's first studies (published in 1939) was a design for a mission then well beyond the capabilities of the times: a manned landing on the Moon. The society's moonship, based on 1930s technology, bore little resemblance in detail to the Apollo spacecraft of 30 years later, but it did demonstrate that lunar travel would one day be possible. In the same spirit, the British Interplanetary Society began Project Daedalus in 1973.

Named for a brilliant craftsman who, in ancient Greek mythology, fashioned wings of wax and feathers to escape from the labyrinth of King Minos, the project is the largest single study of interstellar exploration ever undertaken. The core of the Daedalus study team was a group of 13 scientists and engineers under the leadership of Alan Bond of the United Kingdom Atomic Energy Authority; about 50 others also contributed. The goal of the study was to develop a design for a spacecraft capable of carrying out the simplest possible interstellar mission, an unmanned flyby. The project members specified that, whenever possible, the design should use present-day technology; reasonable extrapolations of near-future technological capabilities might be called upon when necessary.

The Daedalus study was not intended to produce the blueprints for a starship — since no real starship will ever consist of a hodgepodge of 20th and 21st century technology. Instead, it sought to show that interstellar flight can be discussed in sensible terms within the framework of established science and technology. Nevertheless, the Daedalus study provides what may be our best glimpse of the spacecraft that may someday probe the mysteries of the stars.

The target chosen by the Daedalus team is the Sun's second nearest neighbor in space, a red dwarf known as Barnard's star. Barnard's star was chosen because certain controversial photographic evidence suggests that it has planetary companions. It lies 5.91 light-years from the Sun. The choice was somewhat arbitrary; any spacecraft capable of the voyage to Barnard's star could easily make the shorter 4.3 light-year cruise to the Sun's nearest neighbor, the Alpha Centauri triple star system (see "The Three Suns of Centaurus," ASTRONOMY, January 1982). It could also, given a 50% extension of its flight time, reach any star within 9 light-years of the Sun.

Barnard's star appears in terrestrial skies as an obscure ninth-magnitude star in the equatorial constellation Ophiuchus the Serpent-bearer. Astrophysicists believe it is a Population II object, a visitor from the galactic halo that is plunging through the plane of the Galaxy's spiral arms. As a red dwarf, it is representative of the smallest and most numerous class of stars in the Galaxy. Its mass is 0.13 times that of the Sun, or about 100 times that of the planet Jupiter. Its diameter is about one-sixth that of the Sun, or twice that of Jupiter. The star's surface is only half as hot as the Sun's, and it is only $\frac{1}{2000}$ times as bright. If Barnard's star replaced the Sun at the center of our solar system, it would appear only 200 times as bright and one-sixth as large as the Full Moon. Life may be unlikely — or even impossible — on planets of such a star, but no one knows for sure.

Reaching Barnard's star will be a formidable undertaking. If our entire solar system (bounded by the orbit of Pluto) were reduced to the size of a 25-cent piece, the distance to Barnard's star would still stretch longer than a football field. Present-day interplanetary spacecraft such as Voyager or Pioneer would take 100,000 years to cross such a distance. The Daedalus team decided that an interstellar mission could be considered feasible only if it were completed within 50 years or less. To reach Barnard's star in that time, a spacecraft would have to travel at a speed of 36,000 kilometers per second, or 12% the velocity of light. (A craft moving at this velocity would cover the distance between the Earth and Moon in about 10 seconds.) The chemical-powered rockets that propel present-day spacecraft are utterly incapable of reaching such speeds, as are the rockets propelled by solar power

Accelerating away from the fueling base at Jupiter's moon Callisto, the Daedalus ship embarks on its interstellar voyage of discovery. Next port of call — Barnard's Star! Painting by Dick Skover.

and nuclear fission that are proposed for manned interplanetary travel. Only one form of energy is likely to yield the necessary velocities in the near future — nuclear fusion.

Nuclear fusion is the energy source of the stars. In a fusion reaction two lightweight atomic nuclei join, forming a single, more massive nucleus and releasing enormous quantities of energy. The powers of nuclear fusion were first unleashed by humans in 1951 in the detonation of the first hydrogen bomb. For more than 30 years, physicists have struggled to find a way to release fusion energy in a more controlled manner. In the early 1970s, studies began on a promising new method called inertial confinement fusion.

In inertial confinement fusion, a tiny fuel pellet of frozen hydrogen is bombarded from several directions by powerful laser or electron beams. The beams compress and heat the pellet to conditions comparable to those found at the core of the Sun, which triggers a small fusion explosion. A rapid succession of such mini-explosions could provide a continuous source of power. The members of the Daedalus team believe that, given the projected technology of the 21st century, a nuclear pulse rocket based on fusion can provide the velocities necessary for practical interstellar flight.

Fueling a fusion-powered starship would pose serious problems. Only one specific type of fusion reaction, the deuterium/helium-3 reaction, appears feasible for Daedalus. Deuterium, an isotope of hydrogen, is reasonably abundant on Earth and can be extracted from ordinary water. Helium-3, however, is rarer and more valuable than gold. If Earth were the only available source for it, the Daedalus starship — which requires 30,000 tons of helium-3 — could never be economically feasible. By the mid-21st century, however, manned interplanetary flight may be routine. Might we find more abundant supplies of helium-3 elsewhere in the solar system?

Earth and the other terrestrial planets are small, rocky, metallic globes, whose feeble gravity cannot retain much helium. The gas-giant planets of the outer solar system, however, are made primarily of hydrogen and helium. The solar system's largest planet, Jupiter, is a swirling ball of gases 318 times more massive than the Earth. An estimated 17% of Jupiter's atmosphere is helium, and as much as one ten-thousandth of this may be helium-3. To obtain the vast quantities of helium-3 needed for their starship, the Daedalus team has boldly proposed mining Jupiter's atmosphere.

Unquestionably, this is an ambitious project. Jupiter has no solid surface and a gravitational pull 2.7 times that of Earth. The Daedalus study envisions fleets of automated "aerostat factories" plunged from space into Jupiter's atmosphere and suspended beneath giant "hot hydrogen" balloons. About 130 such factory-ships, operating over a period of 20 years, would be needed to extract the necessary amounts of helium-3. The precious fuel would be retrieved by manned nuclear-powered shuttlecraft that would visit the factories periodically. Perhaps the most spectacular — and difficult — mission to which any 21st century astronaut will ever be assigned will be the fiery glide from space down into the churning clouds of Jupiter.

The Daedalus starship itself would be a two-stage, 190-meter tall interstellar rocket. Constructed in space and destined never to enter a planetary atmosphere, the vehicle would lack the streamlined appearance of a Saturn V or the Space Shuttle. Instead, the ungainly assemblage of fuel tanks, equipment, and engines would most resemble a gigantic bunch of grapes.

An enormous hemispherical chamber 100 meters in diameter lies at the base of the ship. Wrapped in magnetic-field coils and encircled by a ring of 75 powerful electron "guns" and an induction coil, this is the first-stage engine. Fuel pellets would be shot into the chamber at a rate of 250 per second from a magnetic pellet gun at its apex. Each pellet would be slammed with a 25-nanosecond burst of electrons carrying more than 100 quadrillion watts of power and would detonate with the force of several tons of TNT. The expanding shell of hot ionized gas produced by the explosion would be redirected by powerful magnetic fields into a jet of rocket exhaust streaming from the rear of the chamber. A small fraction of the jet's energy would be extracted by the induction coil at the base of the chamber to power the next electron pulse.

Above the engine chamber would be a cylindrical 12-sided open frame structure — the first-stage service bay. The service bay would contain several of the engine's subsystems and function as the structural backbone of the first stage. A reflective thermal shield at the base of the bay would protect the ship's systems from the heat of the engine. Six spherical fuel tanks 30 meters in diameter would cluster about the bay. The tanks would contain a total of 46,000 tons of deuterium/helium-3 propellant in the form of 15 billion fuel pellets suspended in a bath of helium-4 and maintained at a temperature of 3° Kelvin. They would be jettisoned in pairs as their fuel is used up.

The base of the Daedalus starship's second stage sits nestled within the upper portion of the first stage service bay. Its engine would be a smaller version of the first-stage engine with a reaction chamber 40 meters in diameter. Unlike the first-stage reaction chamber, the second-stage chamber would be parabolic and would double as the antenna for the spacecraft's radio communications system. The second-stage service bay, like that of the first stage, would be protected from the heat of the engine by a thermal shield and would contain engine subsystems. It would also contain the ship's communications system and a small reserve tank of fuel pellets for final maneuvers as the craft approaches the Barnard's star system. The second stage's four 15-meter spherical fuel tanks would cluster about the service bay, above and to the inside of the first-stage fuel tanks.

Above the service bay is the ship's payload bay, a 450-ton cylinder containing scientific experiments and the master computer. The computer would be located at the central core of the payload bay with scientific experiments and their support equipment on four decks surrounding it. The uppermost deck, the probe deck, would contain 18 detachable planetary and stellar probes. The second deck, the astronomy deck, would contain two 5-meter reflector telescopes, Schmidt cameras, and other optics, as well as two large radio telescopes. These instruments are to be used as the starship approaches Barnard's star to locate and track its planets. The third deck, the probe communications deck, would be crammed with the equipment and antennas necessary for communication with the detached probes. The lowest deck would contain probes designed to study the interstellar medium and two mobile robot repairmen known as wardens. The wardens are controlled by the ship's computer and can make repairs and deploy experiments using multiple robot arms. The payload bay is capped by a 50-ton disk of beryllium metal to protect the ship from erosion by hydrogen atoms and dust grains as it plows through the interstellar medium at 12% light-speed.

The Daedalus team envisions the starship as being assembled at a space manufacturing facility somewhere in the inner solar system. It might take 20 years to design, manufacture, and test — the time needed to mine its fuel from Jupiter. After the ship is assembled, it would be taken to Jupiter for fueling. The ship could be fueled while orbiting Jupiter's moon Callisto. The outermost of the four Galilean moons and the only one that lies beyond the most intense portion of Jupiter's deadly radiation belts, Callisto is a likely base for jovian mining operations.

Before its final departure for Barnard's star, the ship would be sent on one or more test cruises beyond the limits of the solar system. The long voyage would begin when flight controllers were satisfied with the performance of its systems. When the great day finally arrives, high above Callisto the ship's mighty first-stage engine would ignite. A jet of super-hot plasma would stream from the ship's reaction chamber at 10,000 kilometers per second, driving the 54,000-ton craft forward with 1.7 million pounds of thrust. The engine would continue to fire, with only brief pauses for jettisoning empty fuel tanks, for more than two years. At first-stage shutdown, the ship would be traveling at 7.1% of the velocity of light. Explosive bolts would fire and the now empty first stage would be cast adrift. The second-stage engine would then ignite, pushing the remaining spacecraft with 150,000 pounds of thrust for 1.8 years more. Three years and 290 days into the mission, the second-stage engine would fall silent. The ship, now down to 908 tons and consisting of the second-stage engine and service and payload bays, would be traveling at its interstellar cruise velocity of 12% of the velocity of light. The 47-year coast to Barnard's star lies ahead.

At second-stage shutdown, the spacecraft would be 0.21 light-years (13,280 AU) from the Sun. A radio signal transmitted by the ship, traveling at the velocity of light, would take 2½ months to reach Earth — and Earth's reply would not be received by the ship until more than 5 months after the message was sent. By the time the ship reached the vicinity of Barnard's star, 5.91 light-years from Earth, the lag between query and response would grow to nearly 12 years. Starships can never be controlled effectively from Earth. Instead, such craft will need to rely entirely on the intelligence of their onboard computers.

Advances in computer technology are just as important to the feasibility of the Daedalus starship as are advances in rocket propulsion. Present-day spacecraft computers are capable of little more than storing and executing lists of instructions received from their programmers on Earth. The slightest unexpected occurrence — the jamming of a scan platform or the loss of a navigational guide star — leaves them waiting helplessly for new instructions from mission control. Some computer scientists working on artificial intelligence hope to develop computers capable of behaving in a far more flexible and intelligent manner. They believe it will be possible to endow future computers with a humanlike ability to reason, learn, recognize patterns, make decisions, and solve problems. So far, their best achievement has been several chess-playing computer programs capable of defeating all but a handful of the world's top players. This is pretty good, but still well short of what is needed for Daedalus. The designers believe that by the mid-21st century we will have developed computers intelligent enough to replace mission control and take command of a starship.

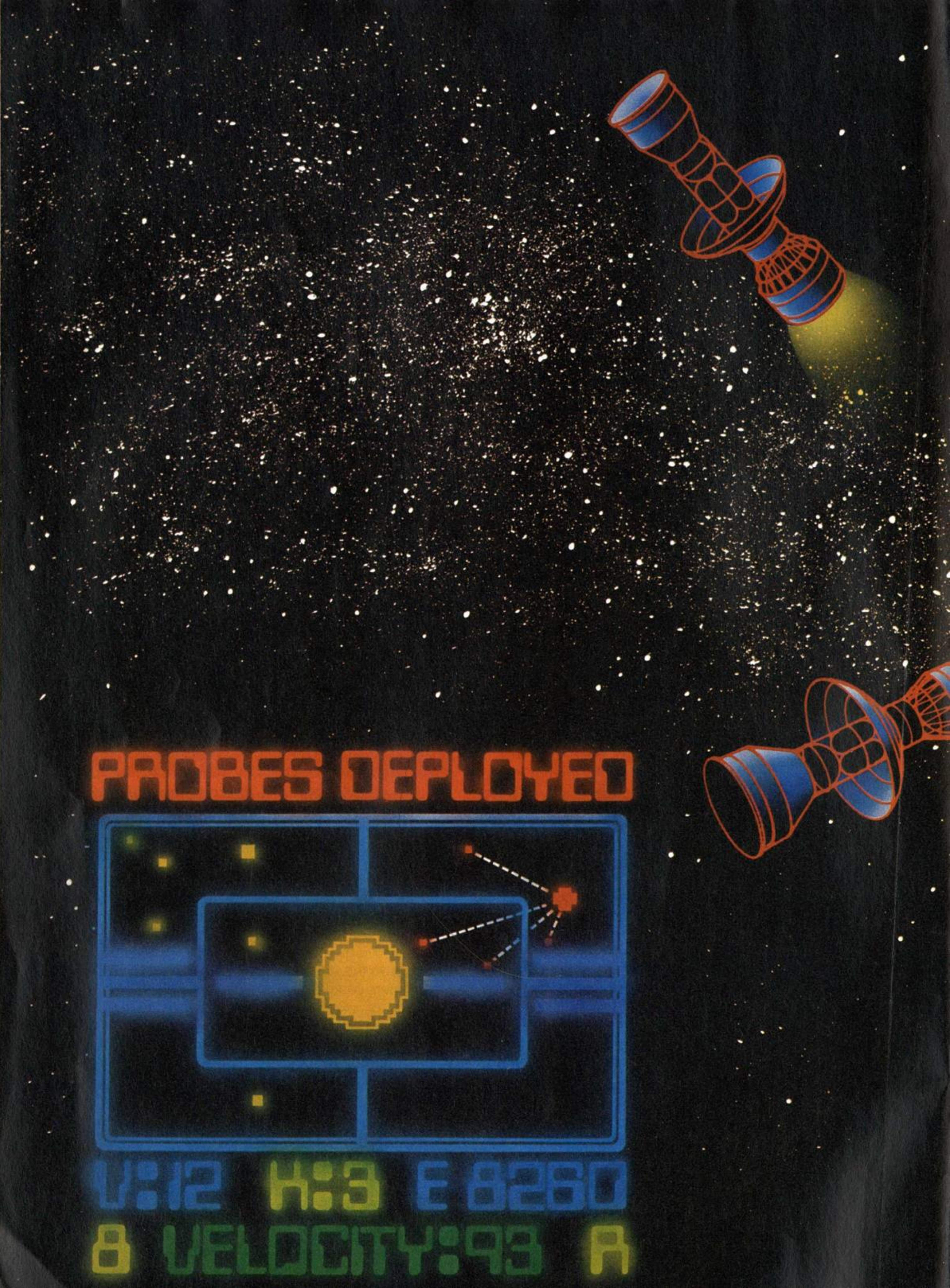
The challenges facing such a computer would be formidable. During the long interstellar journey, it would have to operate, maintain, and even (using the robot wardens) repair the starship, coping with any problems that arise. As the ship approaches Barnard's star, the computer will use data collected by its telescopes and instruments to build up a detailed image of the barnardian planetary system. Based on this picture and on priorities established by its builders back on Earth, it would devise a complete plan for the best possible use of the ship's probes and instruments at encounter. After encounter, it will process the data into a form suitable for transmission to its distant masters.

Long before the Daedalus ship approached Barnard's star, it could begin to reward the enormous technological efforts of its makers with important scientific data. The Daedalus team has identified a number of significant scientific studies that the starship might perform during its five-decade interstellar coast. Through most of the long voyage, Daedalus' large optical and radio telescopes will be available for a variety of uses. They would be uniquely suited for any astronomical observations requiring long, uninterrupted observation time or a radio-quiet environment. Precise measurements of stellar positions, made with Daedalus' 5-meter optical telescope, when compared with similar observations made near Earth, would permit great refinements in our knowledge of the distances to the stars. With such parallax measurements, astronomers could determine the size of the Galaxy to an accuracy of much better than 1%. Daedalus' robot wardens, equipped with their own propulsion systems, could unfurl giant lightweight radio telescope antennas to float freely at distances of many kilometers from the starship. The antennas would be used for wide-spectrum astronomical observations at long wavelengths, far from the radio interference of the solar system.

The Project Daedalus starship would be the largest and most complex engineering feat ever attempted....its target: Barnard's Star, 5.9 light-years away....the unmanned craft is to be built in Earth orbit and fueled at Jupiter....its engines explode 250 H-bombs per second and sustain their thrust for nearly four years....the craft's cruise velocity is 12% that of light....the transit time to Barnard's Star: 50 Earth years....

The Daedalus starship could also probe the interstellar medium surrounding it. Using indirect methods, astronomers have found that the space between the stars is not quite empty. It is filled with an extremely tenuous

Overleaf: Years before its encounter with the Barnard's Star system, the Daedalus ship maneuvers to place four of its probes into trajectories that will take them past some of the planets that lie ahead. Painting by Dick Skover.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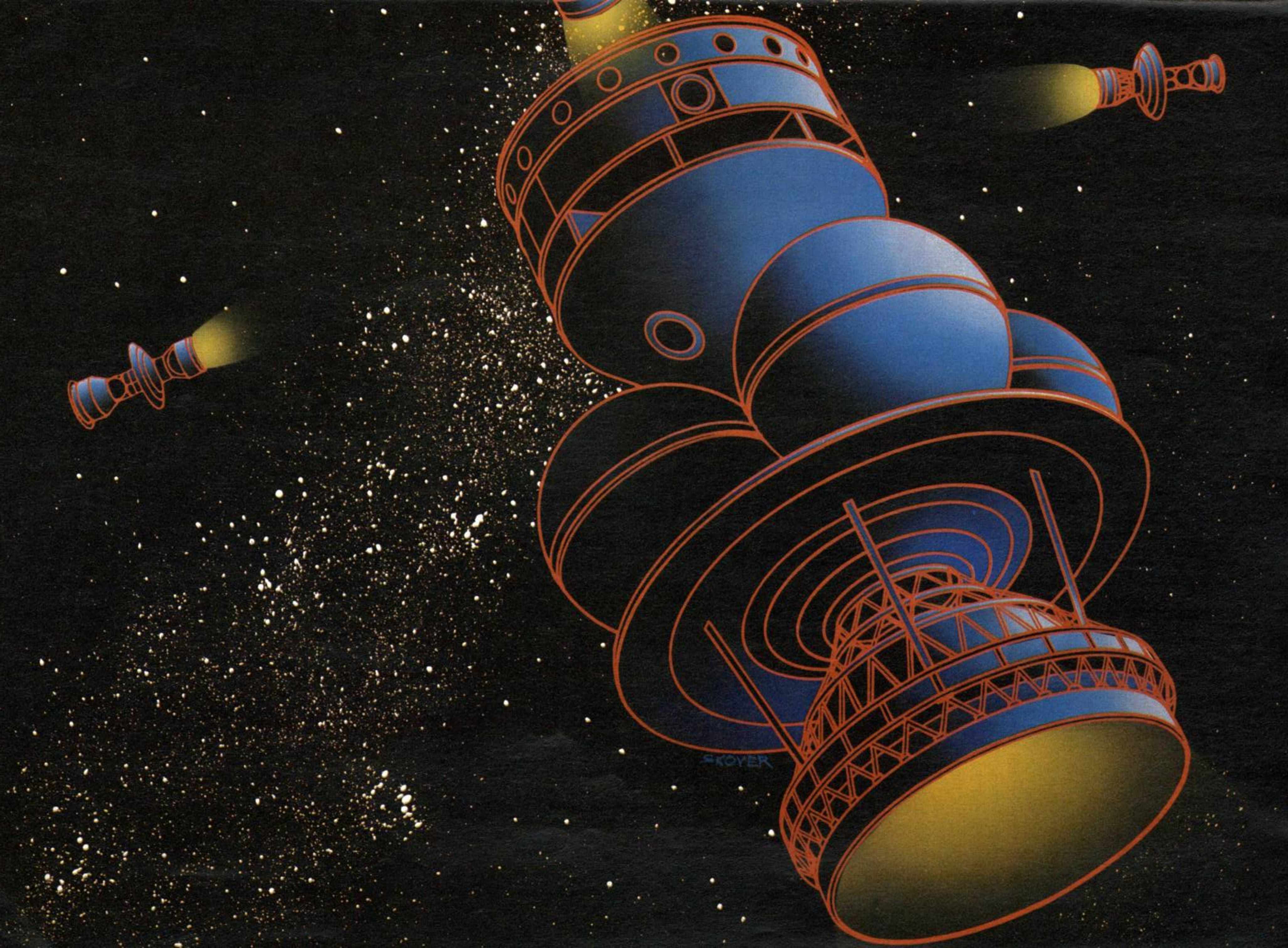

SKOVER

gas consisting mainly of neutral hydrogen atoms (about one atom per cubic centimeter) and is sprinkled with tiny dust grains of unknown composition.

Interstellar medium probes deployed from Daedalus could investigate this material directly along the entire path from the Sun to Barnard's star. The probes would be maintained by the wardens at distances of several tens of thousands of kilometers from the starship's contaminated environment. Their instruments could measure the strength of magnetic, electric, and gravitational fields in interstellar space, as well as the abundances and energies of charged and neutral particles. Studies of the neutral particle environment might include a search for interstellar organic molecules. This could tell us much about the chemistry of interstellar space and perhaps about the origin of life.

Particulate matter could also be scrutinized. An interstellar dust grain, impacting a detector at 12% of the velocity of light, would instantly vaporize in a flash of light. The spectrum of the flash could be analyzed to find the composition of the grain. Other instruments might also be used to probe the interstellar environment.

As Daedalus passes the halfway point in its mission, 25 years after launch and 3 light-years out from Barnard's star, it would begin regular observations of the star. Telescopes and sensors would start the vital search for planets and potentially hazardous concentrations of interplanetary dust. Planets signal their existence in a number of different ways at a number of different wavelengths within the electromagnetic spectrum. They shine at visible wavelengths by reflecting the light of their Sun. They also absorb sunlight, re-emitting the energy in the infrared and microwave portions of the spectrum. The wavelength at which the greatest amount of this thermal radiation is emitted depends on the temperature of the planet. Some planets also emit radio waves at longer wavelengths by non-thermal processes. Charged particles trapped in a planetary magnetosphere are one source of such emission; powerful lightning bolts in a planetary atmosphere are another.

....Three light-years out from Barnard's Star, the ship begins its search for planets....seven years before encounter, the first of the probes deploy to examine the system that lies ahead....despite flybys lasting only seconds or minutes, Daedalus will control and monitor all its 18 probes as they race past their targets....after encounter, the ship will relay the results to Earth where they will arrive six years later.

Daedalus' two Palomar-size optical telescopes would look for planets in the visible and infrared portions of the spectrum. The starship's two 20-meter radio telescopes would search for planetary thermal microwave emissions. Non-thermal radio emissions would be detected with the large free-floating antennas deployed by the wardens. The optical and radio telescopes on the ship would be arranged in opposing pairs across its diameter for interferometry, a technique in which pairs of telescopes can resolve objects too closely spaced to be resolved by either telescope alone. It is likely that Daedalus' first detection of any barnardian planets will be made by infrared interferometry. With present-day technology, gas-giant planets could be detected a few hundred days before encounter and terrestrial planets about fifty days before encounter. The Daedalus team anticipates that advances in instrumentation will improve these figures at least tenfold by the mid-21st century. Early detection and tracking of the barnardian planets are essential to the starship's preparations for encounter.

At encounter the Daedalus starship would perform the most important part of its scientific mission, close-up study of Barnard's star and its presumed planetary system. Many questions about other stars and their planets can only be answered by a starship. The Project Daedalus study has attempted to identify the instruments and exploration strategy necessary to answer them.

Traveling at 12% the speed of light, Daedalus' stay within the barnardian system would be measured in days, and the most useful period of a planetary encounter in minutes. To ensure full coverage during this brief flyby, the starship would dispatch the 18 probes stored on the uppermost deck of its payload bay. The probes would be sent to encounter various planets in the system as well as Barnard's star itself. They would be placed on their proper trajectories using the Daedalus command ship's engine and the reserve tank of fuel pellets in its service bay. Early launch of the probes is important. The closer to the time of encounter that they are sent off, the more fuel is required. Planetary probes should be dispatched from 7.2 to 1.8 years before encounter, according to individual mission requirements as determined by Daedalus' onboard computer.

Each Daedalus encounter probe would be built in the shape of a long narrow cone about 20 meters in length. The wide front end of the cone would be capped by an interstellar erosion shield. An ion rocket engine, placed at the narrow rear end of the cone, would provide thrust for small trajectory refinements. Each probe would carry a small nuclear fission power plant, a computer with limited artificial intelligence, and a communications link with the Daedalus command ship. The probe's instruments would depend on its mission. Of the 18 carried aboard Daedalus, three would be stellar physics probes intended to study Barnard's star itself. Five would be gas-giant planet probes, and five terrestrial planet probes. The remaining five probes would be backups that carry a stripped-down general experiment package and an added onboard propulsion capability. They would be deployed less than 1.8 years before encounter as replacements for any probes that had failed, or to investigate areas of interest that became apparent only after the other probes were sent off.

After surviving 50 years in deep space, one final hazard faces the Daedalus starship and its probes as they race toward encounter: interplanetary debris. The space between and beyond the planets of our solar system is filled with objects ranging in size from tiny micrometeoroids to giant asteroids. The average mass of these particles and their density is much greater than that of the tiny, thinly strewn dust grains of interstellar space. Collisions with even a relatively small piece of this debris at 12% of the velocity of light could destroy the entire spacecraft. It is only sensible to assume that the Barnard's star system contains a similar cloud of debris, against which the Daedalus command ship and its probes must protect themselves.

The Daedalus team has suggested that the vehicles be protected by deploying a dense cloud of tobacco-smoke-sized particles several kilometers in advance of each spacecraft along its flight path. High-speed collision with the cloud would destroy meteoroids up to several hundred kilograms in mass. In order to avoid blocking the probes' instruments during planetary encounters, their cloud shields would be temporarily dispersed by conventional explosive charges. The probes would risk the brief period of planetary encounter unprotected. Shortly before encounter, the vital Daedalus command ship would perform an evasive maneuver to target it toward the far outskirts of the Barnard's star system.

At present, the Sun is the only star whose surface and environment we can study in detail. Other stars differ widely from it in mass, chemical composition, and age. What are their surfaces and environments like? The Daedalus study shows how we can find out. The ship's stellar physics probes, dispatched 1.2 years before encounter, could conduct a thorough examination of Barnard's star. They would use instruments similar to the ones that astrophysicists use to study the Sun now. Images of the star would be obtained at every wavelength of the electromagnetic spectrum. Television cameras would search the star's surface for starspots, granulation, flares, and other possible structural features. Other instruments would map the star's magnetic field and observe the stellar wind of subatomic particles. In order to monitor the stellar wind environment over a longer period than the probe's transit, chemical trails would be released. The dispersal of these artificial comet tails would be probed by the craft's instruments after encounter.

Planetary scientists are limited in their attempts to unravel the complexities of planetary geophysics, geology, meteorology, and climate by the limited number of planets and moons available in our solar system for study. Theories of the origin of planetary systems can only be tested against a single example — that of our own solar system. Exobiologists know nothing of the abundance or scarcity in the universe of planets with conditions conducive to the origin and evolution of life — again, we are working with a sample of one. Daedalus' planetary probes would be a major step toward broadening our knowledge and making it less provincial.

Each instrument on board our present-day Voyager probes would have its counterpart on Daedalus' planetary probes. Each probe would carry television cameras to image the target planet and its moons. Spectrometers, polarimeters, and radiometers working in the ultraviolet, visible, infrared, and microwave regions of the spectrum would probe the chemical composition and temperature of the planet's atmosphere, cloud layers, and surface. Radio astronomy antennas would monitor the planet's radio emission, and laser beams would sound its atmosphere. The deflection of the probe's flight path by the planet's gravity would be tracked to obtain a precise measurement of the planet's mass. To map the planetary magnetosphere in three dimensions, a number of subprobes would be deployed to fly past the planet on separate trajectories. Each, like the main probe, would carry a magnetometer, electronic field probes, charged particle detectors, and plasma probes. They might also make chemical releases for tracking after the probe's departure and carry a limited TV capability for additional planetary imaging or close-up imaging of a planetary moon. Because of the brevity of the encounter, the number of photographs obtained by a probe or subprobe would be limited. Only one planetary hemisphere — the one illuminated by Barnard's star at the time of the encounter — could be mapped.

An interstellar flyby mission would probably not resolve the question of whether life exists on any of the planets of Barnard's star. That would require a far more advanced starship — one capable of decelerating and deploying Viking-like landers to perform TV imaging and complex life-detection experiments on the surfaces of promising planets. Analysis of data from the Daedalus mission, however, could tell us whether conditions conducive to life (proper temperatures, existence of liquid water, etc.) are present on any of the barnardian planets. It could also tell us whether telltale traces of life's activities are present in planetary atmospheres. The large amounts of oxygen in our atmosphere, for example, come from green plant photosynthesis. There is one other possibility — our civilization on Earth produces large amounts of radio-frequency leakage from television broadcasting and military radars. A similar civilization on a planet of Barnard's star would almost certainly be detected by the starship's radio telescopes.

During and after encounter, data from the probes would flow back to the Daedalus command ship to be stored in its computer as a string of about 30 billion ones and zeros. These data could be beamed toward Earth by a transmitter operating continuously for a day and a half. Anxious scientists on Earth would have to wait nearly six years for the radio waves carrying the data to cross the intervening void. It would be received by a large array of radio telescopes on or near our home planet. With its arrival, the direct exploration of the stars will have begun.

The Project Daedalus study has shown us that once controlled nuclear fusion, computer intelligence, and jovian mining become feasible, interstellar exploration becomes possible. The structure, communications system, and even much of the payload for an interstellar flyby spacecraft can be designed on the basis of only present-day technology. A robot starship would open nearby star systems to direct probing by instruments from Earth and vastly expand our knowledge of the universe in which we live. It is also a tremendously exciting endeavor.

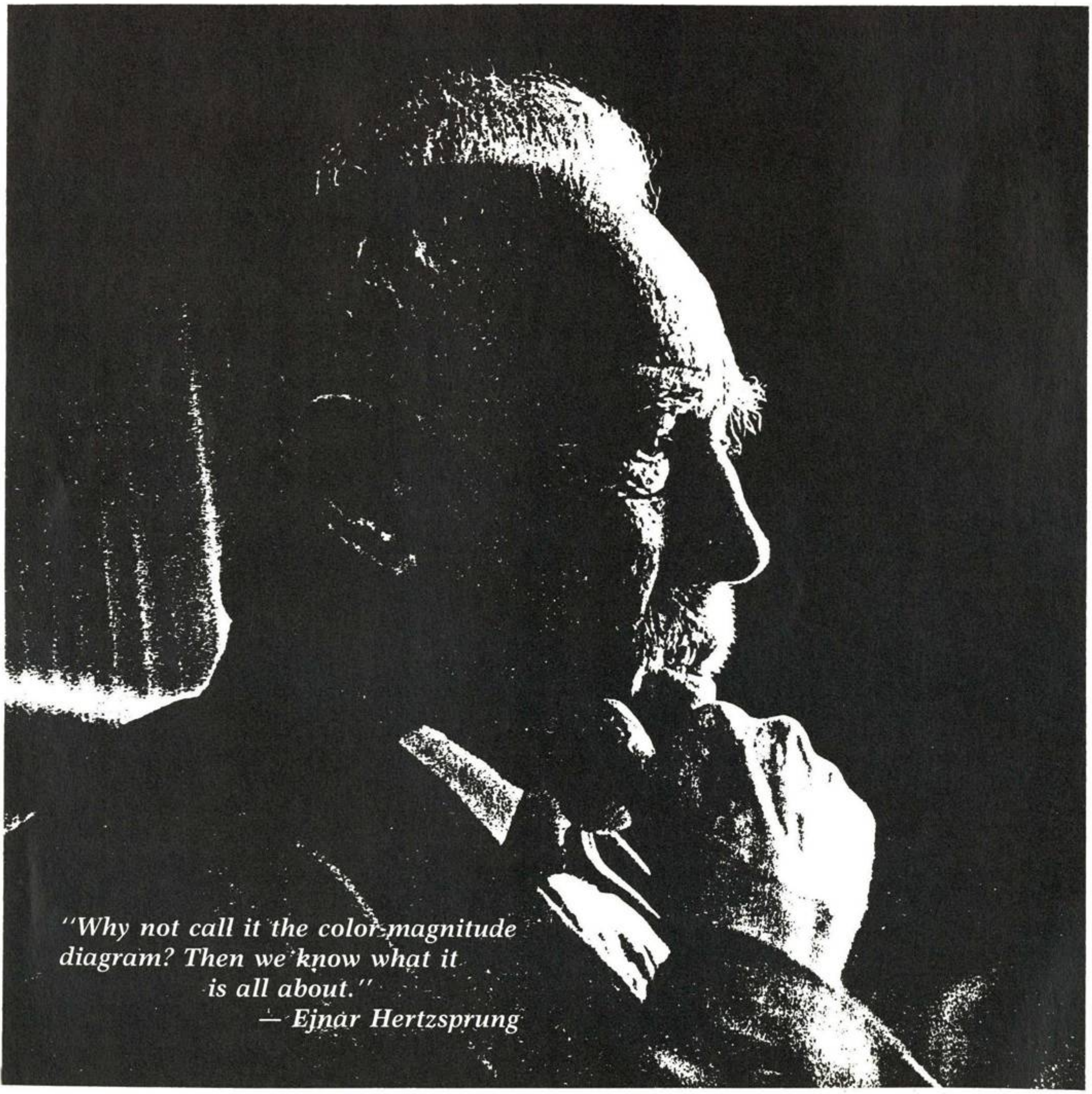
We are privileged to live at the beginning of the space age. The planets are no longer just distant points of light or tiny disks swimming in the eyepiece of a telescope. They are awesome, complex, and mysterious *worlds*. We have seen humans walk the ancient surface of the Moon and may live to see the age of manned interplanetary travel, but if the conclusions of the Daedalus study are correct, few of us alive today will live to see the departure of the first starship and none of us will see the results of the first flyby. The wonders of other planetary systems are reserved for our grandchildren and great-grandchildren.

Beyond lies the immensity of the Galaxy. If our descendants could explore one new star every year, it would take hundreds of billions of years to complete our survey of this immense system, and that would be only the beginning. "Our universe," wrote the ancient Roman philosopher Seneca, "is a sorry little affair unless it has in it something for every age to investigate."

Paul Patton has a B.S. degree in physics and an avid interest in astronomy and space exploration. His article "The Three Suns of Centaurus" appeared in the January 1982 issue.

Decoding the Hertzsprung-Russell Diagram

by Judy A. Getts



"Why not call it the color-magnitude diagram? Then we know what it is all about."
— Ejnar Hertzsprung

Nordisk Pressefoto A/S

In the study of stellar evolution, Hertzsprung-Russell diagrams are absolutely essential. From this simple graph of stellar luminosity against surface temperature, astrophysicists can determine a star's age, size, mass, chemical composition, and often its distance. The development of the H-R diagram just before World War I revolutionized our understanding of the way stars age.

Early in this century, our knowledge of the life-history of stars was much more limited than it is today. One theory of stellar evolution suggested that a star formed as a cool giant of spectral type M. As it aged, the star contracted and grew hotter, changing its spectral type from M to K, then G, F, A, and B as the temperatures of its surface climbed. Late in its evolution, the star's surface temperature decreased and it reversed its earlier path through the spectral classifications, cooling and contracting until it became a lump of matter devoid of heat and light.

Most astronomers did not, however, agree with this scheme; they believed instead that the hot blue B-type stars were examples of stellar youth, growing cooler and redder with age. Around 1905, the Danish astronomer Ejnar Hertzsprung observed that cool stars of spectral class M could be divided into two types. Some were giant stars with luminosities 100 times that of the Sun, while other stars — dwarfs — shone with less than 1/1000 of the Sun's brightness. A few years later, the American astronomer Henry Norris Russell, unaware of Hertzsprung's work, recognized the great differences in luminosity between red stars and extended the idea of "giants and dwarfs" to yellow stars. The independent work of both astronomers proved a correlation between stellar brightness and surface temperature, paving the way for the H-R diagram. Much later in the century, astronomers discovered the reasons behind the initially perplexing graph stars formed when plotted by temperature and brightness.

The H-R diagram plots two properties of a star: its luminosity (total energy emitted at all wavelengths) against spectral type (the classification of its spectrum according to the absorption lines it displays). Luminosity is frequently measured in solar units; a star with a luminosity of 10 is ten times brighter than the Sun, for example. But it can also be measured as absolute magnitude, the apparent brightness of the star if it were placed 10 parsecs (32.6 light-years) away. According to convention, astronomers plot luminosity on the vertical axis of the H-R diagram.

Surface temperature is plotted along the diagram's horizontal axis. Astronomers can estimate a star's surface temperature from its spectral type. For instance, a red star whose spectrum shows the presence of molecules must have a rather cool surface temperature — around 3,000° Kelvin. On the other hand, spectra from the hottest of the blue-white stars may display a few dark bands from ionized hydrogen, indicating a surface temperature of 50,000° K. Our Sun, with its surface temperature of 6,000° K, is a relatively cool star. Astronomers plot surface temperature

". . . it seems clear that this difference, at least, is real, and that there is a real lack of red stars comparable in brightness to the Sun."
— Henry Norris Russell

AIP Niels Bohr Library

along the H-R diagram's horizontal axis.

Curiously, the diagram plots surface temperature so that it increases from right to left, instead of in the more conventional manner of left to right. But this eccentricity simply owes its existence to the manner in which the diagram developed.

When Hertzsprung and Russell first plotted a large sample of stars by their spectral type and luminosity, they found that over 90 percent of all stars lie along a narrow, S-curved band that runs diagonally through the center of the graph. This band — called the main sequence — contains such stars as Sirius, Vega, Alpha Centauri A and B, and the Sun.

Above the main sequence lies another band, consisting of yellow and red giant stars 100 times more luminous than the Sun. This is the giant branch, to which the Sun will eventually evolve. Higher up on the graph, in the extreme low-temperature, high-luminosity region, lie the extraordinarily bright yellow and red stars like Betelgeuse and Antares — the supergiants. The supergiant branch is not sharply distinguishable from the giant branch. The most massive stars eventually evolve here as they expand and cool.

Over in the high-luminosity, high-temperature part of the diagram, reside the blue supergiants — luminaries like Rigel, Deneb, and Canopus. White dwarfs, the densest objects next to pulsars, have high surface temperatures but low luminosities; they appear in the diagram's low luminosity, high-temperature region.

But establishing that stars "clump" on the H-R diagram gives no hint of why these particular areas exist or how stars evolve. When Russell devised the diagram, he assumed that a star began its life as a cool giant star which gradually shrank through gravitational contraction to become hotter and denser. Likewise, he speculated that stars evolved through the high-luminosity, low-temperature region to the high-luminosity, high-temperature portion — right to left across the top of the H-R diagram — and then slid down the main sequence as they cooled. But all attempts to understand the distribution of stars on the H-R diagram were unsuccessful until astrophysicists managed to model the internal structure of stars.

It had become obvious by the 1930s that stars produce energy by thermonuclear fusion — smashing together light atomic nuclei to create heavier nuclei and liberate energy. In the Sun and all the stars on the main sequence, hydrogen nuclei (protons) in the core bind together to make helium nuclei. As a star ages, the chemical composition of its core slowly changes — the dominant element in the core slowly shifts from hydrogen to helium. The mass of a star controls the rate at which this aging process occurs. The changes in the core also produce changes in the surface temperature and luminosity of a star as it ages, so stars in different phases of their life should, logically enough, appear in different places on the H-R diagram. Since mass determines the rate at which a star's internal changes occur, it also determines where on the diagram we would plot a star throughout its life. Astronomers realized this when they focused their interest on clusters of stars.

In a cluster, all stars have roughly the same age and chemical composition, since they presumably formed at the same time from the same cloud of dust and gas. But in spite of their shared genesis, the members of both globular and open star clusters exhibit a wide range of luminosity and spectral class. If the prevailing idea of stellar evolution ("hot B star to cool, red M star") were correct, the range of intrinsic brightness and spectral type would be far smaller. So the great differences in temperature and luminosity of stars in the same cluster must be attributed to some difference in each of the stars. Since mass controls the way a star changes through time, a star's initial mass must be among the most important quantities. Differences in initial chemical composition are of secondary and comparatively minor importance in determining a star's evolutionary path.

Stellar masses do not vary as much as stellar luminosities, though. Indeed, the masses of most stars do not differ much from the mass of the Sun. But mass is such an important property that even slight differences can account for great variations in a star's internal structure and evolution.

A star spends most of its life on the main sequence, that broad diagonal band in the center of the graph. Since every star spends the largest fraction of its life on the main sequence, this region represents an area with the greatest probability of containing a star. The main sequence contains the stellar majority because you're more likely to find a star there than anywhere else. The length of time a star remains on the main sequence depends upon its mass. A low-mass star burns its fuel more slowly and therefore remains on the main sequence longer than a star of greater mass. You can roughly compute the length of a star's main sequence life by raising the star's mass (relative to that of the Sun) to the -2.3 power and multiplying that number by 10 billion. That is, the time in years a star spends on the main sequence is roughly 10^{10} (star mass / Sun's mass)$^{-2.3}$.

The H-R diagram was the first astronomical tool to define the stellar "prime of life" of the main sequence. Astronomers know much more about the main sequence than the other branches of the diagram simply because most stars — including our own Sun — inhabit this stellar phase.

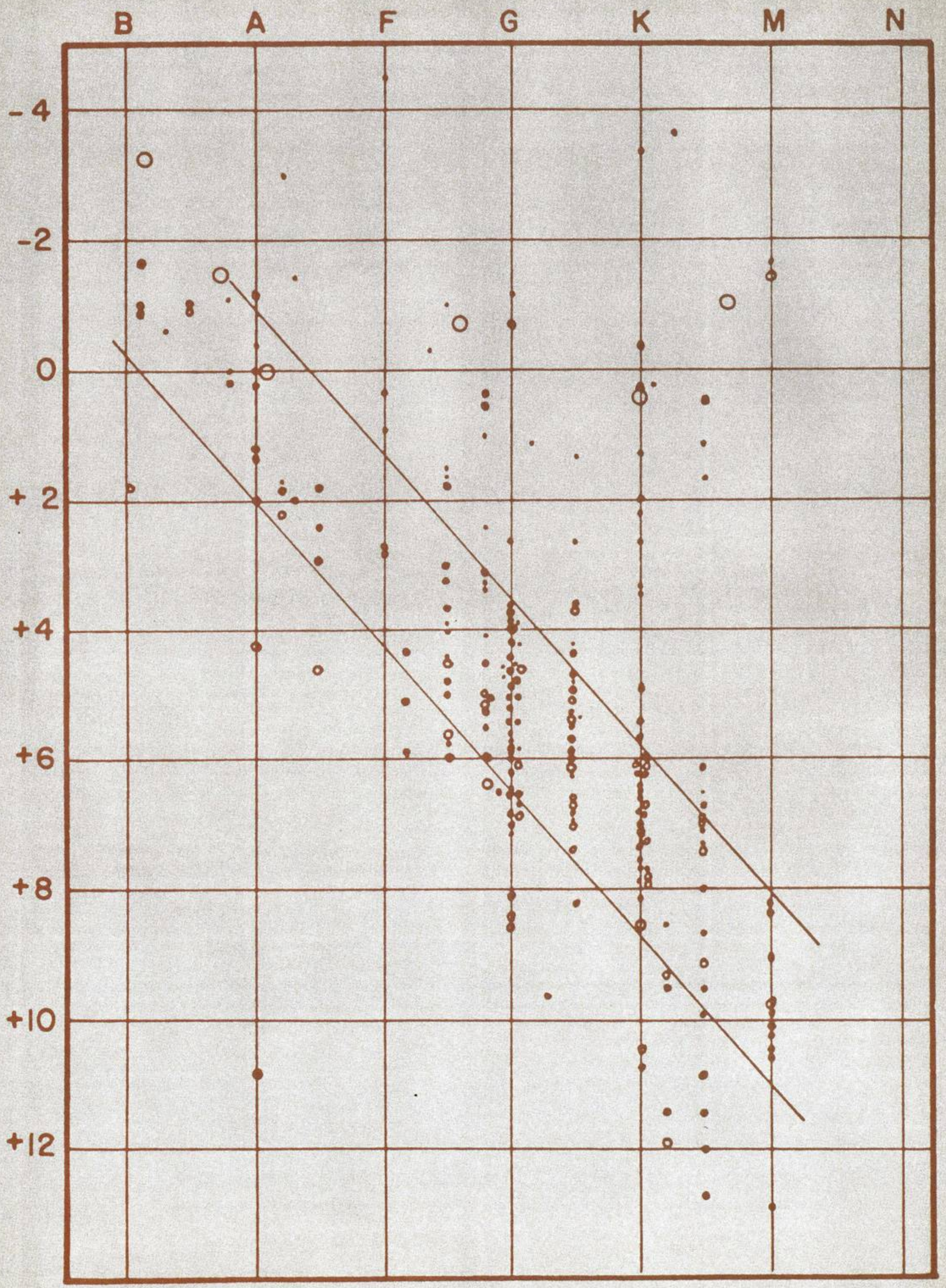
A star begins as a collapsing cloud of gas and dust. It may take a fledgling star anywhere from 20 to 800 million years to complete this slow process of gravitational contraction, its luminosity and surface temperature continually increasing. The star settles on the main sequence when the temperature of the stellar core climbs high enough to sustain the reactions of thermonuclear fusion that convert hydrogen into helium.

The time it takes the core to reach these temperatures depends on the star's initial mass. Therefore the more massive a star, the more rapidly it descends to the main sequence. A massive star will also land higher on the main sequence — that is, it will be brighter — than a star of lower mass since a higher-mass star burns its fuel more rapidly. A star one third of the Sun's mass, for instance, joins the main sequence as a faint red M-type dwarf and will stay there for many billions of years. A 20-solar-mass star, on the other hand, reaches the main sequence as a brilliant blue-white type O star, but remains on it for just a few tens of millions of years.

> ***When Hertzsprung and Russell plotted stars by spectral type and luminosity, they found that over 90 percent lay along a narrow, S-curved band.***

Once on the main sequence, a star has attained maturity. Gradually, though, its core becomes "polluted" with helium nuclei, the waste product of hydrogen fusion. As the star ages, the core contracts, becomes hotter, and eventually must begin another set of fusion reactions involving the helium residue. When this change of nuclear fuels occurs — and, once again, the length of time needed for this to happen depends on mass — the star's surface temperature, luminosity, and radius change so dramatically that, if plotted on the diagram, it would fall into one of the giant branches, not the main sequence.

How does this shift in fuels occur? Let's take a look at the way a star like the Sun evolves. As it burns and depletes the hydrogen in its core, the area undergoing nuclear fusion spreads into regions beyond the core where hydrogen is more abundant. Such a star begins the changes in brightness, temperature, and size that initiate its move off the main sequence. As the reactions move away from the core in a shell, no energy supports the core and it collapses and heats up. The increased temperature heats the shell undergoing hydrogen fusion, so the reactions go faster and produce more energy. In order to compensate for the increased heat of its hydrogen-burning shell, the star expands; the outermost regions of the star begin to cool. As they cool, the low-temperature outer layers become somewhat opaque to radiation. Energy must leave the core by setting up convection in the gas: hot gas near the core rises; cool gas near the surface descends. Some 500 million years after leaving the main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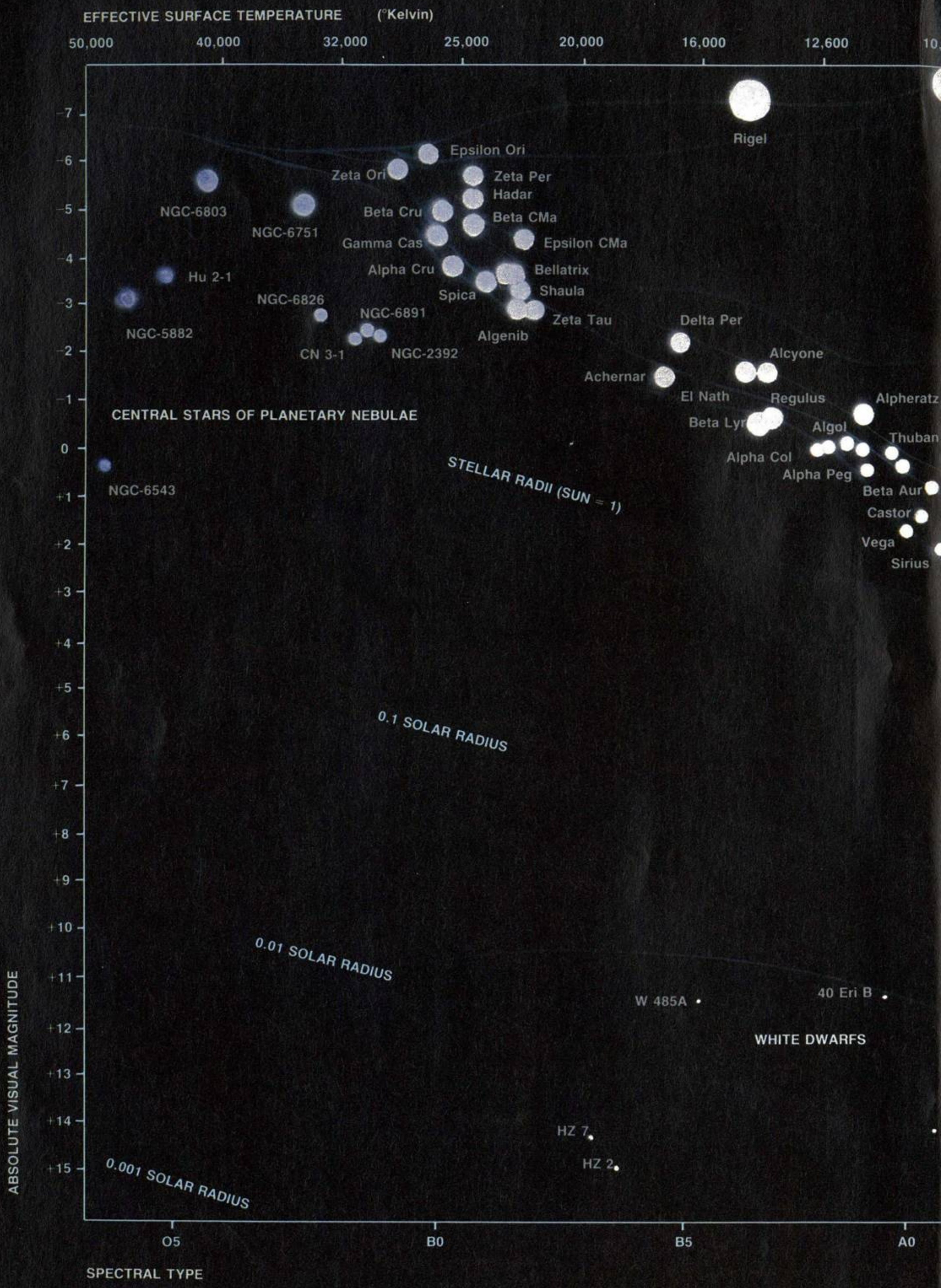
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ABSOLUTE VISUAL MAGNITUDE
-7
-6
-5
-4
-3
-2
-1
0
+1
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Rigel
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Achernar
El Nath
Regulus
Alpheratz
CENTRAL STARS OF PLANETARY NEBULAE
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Algol
Thuban
Alpha Col
Alpha Peg
NGC-6543
STELLAR RADII (SUN = 1)
Beta Aur
Castor
Vega
Sirius
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0.01 SOLAR RADIUS
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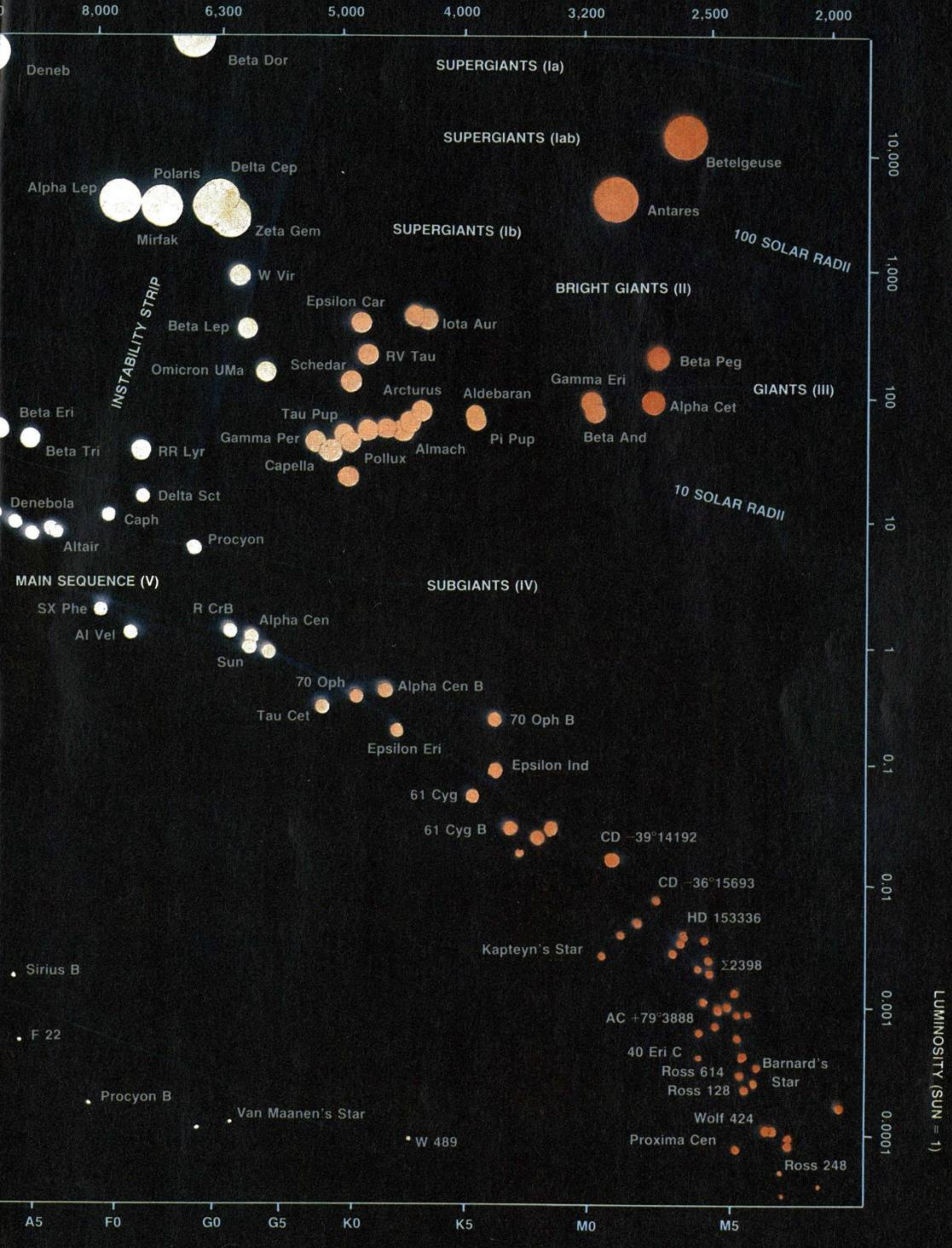
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Procyon
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Barnard's Star
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Ross 128
Procyon B
Van Maanen's Star
Wolf 424
W 489
Proxima Cen
Ross 248
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1,000
100
10
1
0.1
0.01
0.001
0.0001
LUMINOSITY (SUN = 1)
A5
F0
G0
G5
K0
K5
M0
M5

sequence, the Sun will be 1000 times brighter, 100 times larger (engulfing Mercury!), and its surface temperature will have dropped by a factor of two. Our Sun will then be a red giant.

Over the half-billion year transition from main sequence star to red giant, the star's core steadily contracted and heated. When it reaches the necessary temperature, helium fusion violently ignites throughout the core, which rapidly expands, cools, and stabilizes. Astrophysicists call this violent ignition of helium fusion the helium flash. Carbon, the end product of a long string of thermonuclear reactions, now begins accumulating in the star's core. Convection may dredge up carbon-rich material from deep within the star and bring it to the stellar surface. Helium now burns in the star's core, while hydrogen fuses in a shell around the core. Plotting the Sun at this stage of its evolution on an H-R diagram, we would see that the great changes in luminosity and temperature have pushed it far from the main sequence and into the low-temperature end of the giant branch.

After 50 million years of helium burning, the region of nuclear fusion must again move out of the core. Now a hydrogen-burning shell encloses a helium-burning shell that surrounds an inert carbon core. This situation may last for another 500 million years.

Below the main sequence is the low-luminosity, high-temperature realm of the white dwarfs. They represent stars that have survived the instabilities of the giant phase, lost much of their mass by blowing stellar "winds" of charged particles from their surfaces, and formed spherical shrouds of gas — planetary nebulae — around themselves. They are literally burnt out. No nuclear reactions heat their cores. They will slowly cool over the eons, fading into oblivion.

Astronomers don't know much about stellar evolution from the red giant branch to the white dwarf phase. Stars like the Sun will probably eject their outer layers to form a planetary nebula. This eruption lays bare a hot core which excites the ejected material and makes it glow. The hot central star of the nebula may be 10,000 times brighter than the present-day Sun, with a surface temperature of several hundred thousand degrees. It now resides in the very hot, very luminous region of the H-R diagram. Slowly, over a few billion years, the central star cools, its luminosity and surface temperature fall, and the stellar remnant joins the stellar cinders of white dwarfs — perhaps two billion years after leaving the main sequence.

> *Each twist and turn in the track a star makes on the diagram reflects changes in its internal structure.*

Things happen a bit differently for stars slightly more massive than the Sun, even though they undergo the same internal changes as Sun-like stars during the post-main sequence stages of their evolution. Let's look at how a 5 solar mass star — for example, Regulus in the constellation Leo — evolves away from the main sequence. At present, it burns hydrogen in its core, but unlike the Sun, the process used to fuse hydrogen nuclei into helium uses carbon as a catalyst. This series of reactions, called the CNO cycle, requires higher temperatures than the fusion reactions in the Sun. Stoked by high core temperatures, the CNO reactions use up the hydrogen in the core of Regulus just 60 million years after they begin. Because it burns its fuel more quickly, a main sequence star of 5 solar masses is far hotter and more luminous than a one solar mass main-sequence star.

When the central hydrogen fires run low, hydrogen burns in a shell around the core. The star expands, its luminosity increases, its surface temperature drops — all clues to its changing position on the H-R diagram. As the star approaches its red giant phase, the inert helium core begins the slow contraction that will eventually start new fires within it. After about two million years, helium nuclei in the core become hot enough to fuse into carbon nuclei. Thus far, the steps have been essentially the same for the Sun. But for stars like Regulus, helium ignition begins very gently, in marked contrast to the violent helium flash that will occur inside our Sun. The renewal of core burning quickly decreases the star's luminosity and increases its surface temperature. But the star grows hotter and brighter over the next 15 million years as helium fuses to carbon in the star's core.

Helium burns in the core, and hydrogen fuses in a shell around the core. But as the core's helium supply becomes depleted, the star's luminosity and surface temperature decrease; it contracts, heats up, and ignites helium fusion in a shell around the core and inside the hydrogen burning shell. If we plot these changes on an H-R diagram, the star makes a track that loops toward the left (higher temperatures) and upward (higher luminosities). As the star's energy source (fusion of hydrogen in a shell, core helium, or shell helium) begins to fail, the track loops down and to the right — that is, toward lower luminosity and surface temperature. With each new energy source, the star becomes hotter, brighter, and smaller for a while, then it fades, cools, and expands. Each loop occurs at slightly higher luminosities than the last, since each new reaction requires higher temperatures.

Where does it all end? Astronomers aren't quite sure what happens after a star as massive as Regulus starts fusing helium in a shell around its inert carbon core. If the star loses enough mass along its tortuous evolutionary path, it may just slough off its outer layers to make a planetary nebula and become a white dwarf.

But if its mass is large enough, the star violently explodes, becoming hundreds of millions of times more luminous than it was as a red giant. Regulus will eventually ignite its carbon core, but this "carbon flash" may be violent enough to destroy the star. Astronomers believe that stars with masses greater than six times that of the Sun may become such supernovae — violent stellar explosions that herald the births of neutron stars or black holes.

What about stars that are still more massive, say 10 or 20 Suns? They evolve in much the same way as Regulus, but when they reach the red giant phase their luminosities are so great (10,000 Suns!) that they can only be called supergiants. Unlike a star of 5 solar masses, however, these Suns manage to ignite carbon fusion without the violence of a carbon flash. Oxygen and silicon, the products of carbon fusion, collect in the core, and in time they too will burn. Stars like Betelgeuse, a 10 or 20 solar mass red supergiant, will eventually form a multi-layered interior — an extended hydrogen envelope surrounding shells of hydrogen, helium, carbon, oxygen, silicon, and magnesium fusion, all around a core made up of nickel and iron nuclei. As each fusion process turns on, the star's luminosity and surface temperature increase. Their tracks on the H-R diagram reflect these changes; the star dances back and forth between high and low surface temperatures. On the whole, though, the luminosity of the star rises — our twisted plot of the star's physical changes slowly climbs up the graph.

Once again, astronomers aren't sure what happens beyond this point. Nickel and iron nuclei cannot undergo fusion, and without thermal support the star must collapse. Astrophysicists believe that this final collapse may result in a supernova explosion, but our understanding of the precise outcome depends on complicated computer simulations of the way stars evolve.

Each twist and turn in the track a star makes on the diagram reflects changes in its internal structure. By plotting actual stars on the H-R diagram, astronomers discover observational constraints which the mathematical models created by theoreticians must address. The H-R diagram has already led us toward a fairly detailed, though far from complete, knowledge of how stars form, live, and die. The creation of the diagram seven decades ago by Hertzsprung and Russell may be called the most important synthesis in astrophysics. And as we come to understand the stellar life cycle more clearly, the diagram will continue to provide a precise check on theoretical notions about the evolutionary transformations of the stars.

Judy Getts is a freelance writer living in Chicago.

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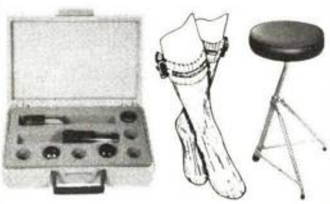

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ASTRONOMY FORUM

The Stars at Night are Big and Bright, Deep in the Heart of Texas

As I drove down I-94 from Milwaukee toward O'Hare International, I could feel the excitement building. After all, I had worked hard to take care of all of my responsibilities for the coming week, and now the second Texas Star Party was a mere five hours away. When the DC-10 bound for Dallas left terra firma, all I could think about was the great time I had last year, at the first TSP. This gathering of several hundred amateur astronomers has a special place in my heart: unlike Stellafane, Riverside, and the Astronomical League conventions, where paper sessions and amateur telescope making dominate, the TSP crowd arrives with one thing in mind. They come to observe. They come because the inky black skies at the Prude Ranch in Fort Davis, Texas — located almost in McDonald Observatory's backyard — offer the best chance for serious observing they'll have for months and even years.

The 13.1-inch Dobsonian Binoculars.

Lee Cain

The time passed. After gulping down lunch, I changed planes in Dallas and headed westward for Midland, where I met Alan Goldstein — Chairman of the National Deep Sky Observers Society — and my Toyota rent-a-car. We talked about where deep-sky observing is and where it is going, and slowly approached the ranch, becoming more and more elated with anticipation. It was hot as we drove into the Davis Mountains, but the scenery was gorgeous: shrub-like trees scattered around the sandy basins shone in the glaring sunlight, mammoth outcrops of rock towered overhead, and indeterminate little creatures scurried across the road every which way.

Slightly after dinnertime on Tuesday, June 7, we pulled through the Prude Ranch gate, which declared, with genuine Texan scale and enthusiasm, "WELCOME TO THE TEXAS STAR PARTY." We had scarcely turned off the engine before George Ellis, the TSP coordinator, appeared and greeted us. "It's been raining like hell the past couple of days," said George, as I looked up at the clearest, bluest skies I had seen in months, "but I think we're in for a good show tonight."

Indeed we were. As twilight began and Venus and Jupiter appeared, dozens of bodies ran helter-skelter to make sure that drives were working, film was loaded, eyepieces were clean, and red flashlights worked. (As at any proper star party, lights other than red filtered ones are prohibited, and normally peaceful amateur astronomers become violent at the sight of a bright light.) Soon after the onset of semi-darkness, cheers of "There's Omega Centauri!" and "Saturn is fantastic!" permeated the warm, breezy air. I wandered around and looked through many telescopes, as impressed as ever with the darkness and excellence of seeing in the Davis Mountains. When astronomical twilight ended, Venus — hanging low in the west — cast easily visible shadows and interfered with observing faint galaxies. It had been a long day of travel, so after looking at lots of deep-sky objects, I decided to call it an early night. I fell asleep around 4:00 a.m., watching bright meteors fall over me, my sleeping bag, and the dusty Texas ground.

Although most of the 400 or so attendees stayed up to observe as long as they could, Wednesday was the day when the Texas Star Party really got underway. Astronomers have to do *something* during the day, so the paper sessions began in the afternoon. This was the day for photometry, a current subinterest in backyard astronomy that has blossomed during the last couple of years. After I rounded up my friends involved with DEEP SKY magazine — Goldstein, Brian Skiff, David Levy, Doug Wereb, and Jack Marling — we were treated to some interesting dialogue. Ron Price of the Texas Astronomical Society told us about his dual channel photometer; Art Sweeney presented a paper on high-speed photoelectric occultations in lieu of Peter Chen of the University of Texas; Rick Binzel of the University of Texas told us about asteroid photometry at McDonald; and Greg Henry — the man in charge of McDonald's telescopes — spoke on RS Canum Venaticorum stars, eclipsing binary

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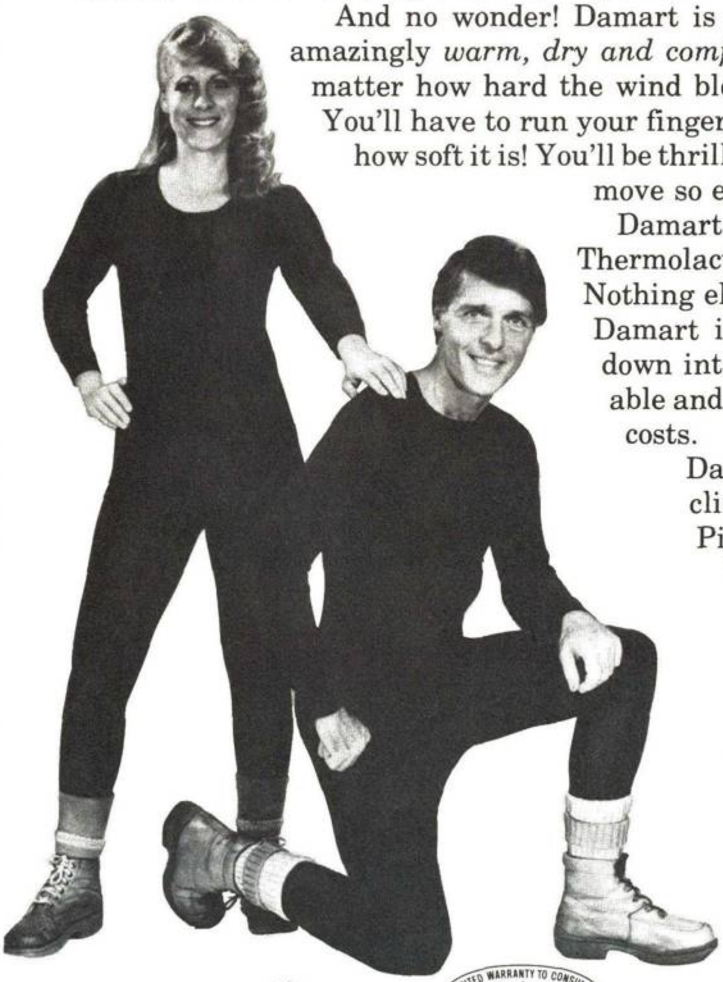

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systems that have yet to undergo mass exchange.

After the talks, Rick Binzel gave us a tour of McDonald Observatory, located on Mount Locke, some five miles from the star party. Rick took us through the 82-inch Otto Struve telescope dome, the more modern 107-inch reflector housing, and ended by showing us the 36-inch scope, where he prepared for photometry work that night. The view from the 107-inch catwalk was astonishing: we saw a small brush fire blazing away and hoped someone else knew about it; Harvard's 85-foot radio dish lay below in the valley; and a Texas-sized jump away was the flattened mountaintop on which Harlan Smith — director of McDonald — plans to place a 300-inch reflector. The observatory is regularly open to visitors and is a sight that shouldn't be missed — if you go there, you'll get a real taste of what professional astronomy is all about.

As we drove back down the mountain toward the ranch, clouds rolled in — not ordinary, non-threatening clouds. Big ones. It looked gloomy, but we went back; swallowing hard as we looked skyward, we optimistically predicted that we'd be observing before midnight. Back at the ranch, twilight had started, and a few diehards hadn't covered their telescopes. Kevin Medlock trained his fine 6-inch refractor on Jupiter, which lay to the southeast only a few degrees above a mountaintop. As we peered through the eyepiece to a slightly soft image, buckets of rain fell from straight overhead. This was the first time I had ever observed in the rain! People ran this way and that, covering telescopes and trying to stay dry; we sought refuge on the porch of a cabin, appeasing the invaded tenants by playing guitar and singing Beatles songs.

It cleared up after a while, and observers gradually uncovered their telescopes, once again gearing them up for new, unexpectedly fine sights. Our little group of roving deep-sky observers — we didn't bring telescopes — wanted to test the magnitude penetration using large instruments. Knowing exactly where to look and using high power, we saw the 15th magnitude supernova in Seyfert galaxy NGC-4051, the 16th magnitude QSO known as Markarian 205 (apparently connected to a normal galaxy), the central star in the Ring Nebula, and many other sights. Then, as tradition would have it, we got tired and passed out, watching meteors under the velvety black skies.

As chilled as I was when I fell asleep, I awoke to a boiling sauna, which I discovered was the interior of my sleeping bag. We barely had time to jump in and out of the ice-cold pool and grab a bite of lunch before Doug Wereb presented a talk on Leander McCormick Observatory in Virginia. An old friend of mine, Doug is a recent faculty addition to McCormick; he is interested in photometry and astrometry, among other things. His colorful tour of the observatory captivated the audience, most of whom were hungry for information on what happens with the big telescopes.

Norm Sperling, proprietor of "Everything in the Universe," presented a useful talk on what amateur astronomers seem to be interested in and why. His conclusions: planetary observing is less popular than it used to be, deep-sky observing is more popular than it once was, and computers in astronomy are the hottest things around. Why is this? Planetary observing lacks the variety that deep-sky observing offers, and large, short-focus telescopes — tailor-made for diffuse extended objects — are the big sellers these days. Why is so much being done with computers in amateur astronomy? Well, just look around. Small computers are invading *everything*, so it makes sense that they're permeating backyard astronomy, as well.

Robert Reeves

McDonald's 82-inch Otto Struve reflector.

After Norm's talk, I got together with Alan Goldstein and Walter Scott ("Scotty") Houston, author of "Deep Sky Wonders" in *Sky and Telescope* magazine, and we gave a seminar on deep-sky observing and astrophotography. There's lots of interest in this area: we fielded questions ranging from "Which is better: a pair of 13-inch binoculars or a single 29-inch mirror?" to "What telescope would you buy if you had $3,000 to spend?" Well, some of the questions were more pertinent. We didn't have all the answers, but suggested options as best we could. Scotty's rapier wit livened the affair, and we ended with enough time for a relaxed dinner before two especially important papers, to be given later in the evening.

When we arrived back at the ranch, Geoffrey Burbidge, director of Kitt Peak National Observatory, was already underway. He detailed work being done with instruments at Kitt Peak and how things will work in the future, and enlightened the audience about the ways of big telescopes and serious research. Because of the potential light pollution from Tucson, no further big scopes are planned for installation on Kitt Peak. But that's not the case for Burbidge's colleague, Harlan Smith, director of McDonald Observatory. He showed the crowd what's happening up on Mount Locke and tantalized them with the plans for the 300-inch Texas Telescope. When this telescope is completed, it will — if only for a short time — be the largest in the world. Both Burbidge and Smith are excellent communicators, and talking to them you get a feeling of security, knowing that this science of astronomy is in capable hands.

Friday, the 10th of June, was the day for papers on deep-sky astronomy. The National Deep-Sky Observers Society (NDSOS) held their annual convention along with the star party and encouraged delegates to join up. The NDSOS currently sponsors projects such as observing the Herschel list, selected IC objects, Barnard dark nebulae and watching for supernovae in galaxies. For $6 sent to Alan Goldstein (3430 Bryan Way, Louisville, KY 40220) you can get their bi-monthly newsletter and stay in touch with other deep-sky observers.

Jack Marling of Lumicon, Inc. offered many helpful tips, first speaking on observing the southern Milky Way, and then on using Kodak's new VR-1000 ultra-fast color print film. Most amateurs who have used this new emulsion like it very much — it will probably be a stock astrophotographic film a couple of years down the road. Brian Skiff of Lowell Observatory spoke on determining integrated colors and magnitudes of open star clusters, a project he is undertaking with a small computer and Lowell telescope data. Alan Goldstein told about his project of tilting negatives of obliquely-viewed spiral galaxies to simulate their face-on appearance. I told the audience about observing high-energy "active" galaxies — stellar systems that show violent internal dynamical activity, like Centaurus A, M-87, BL Lacertae, and 3C-273. Robert Reeves of the San Antonio group presented a nice paper

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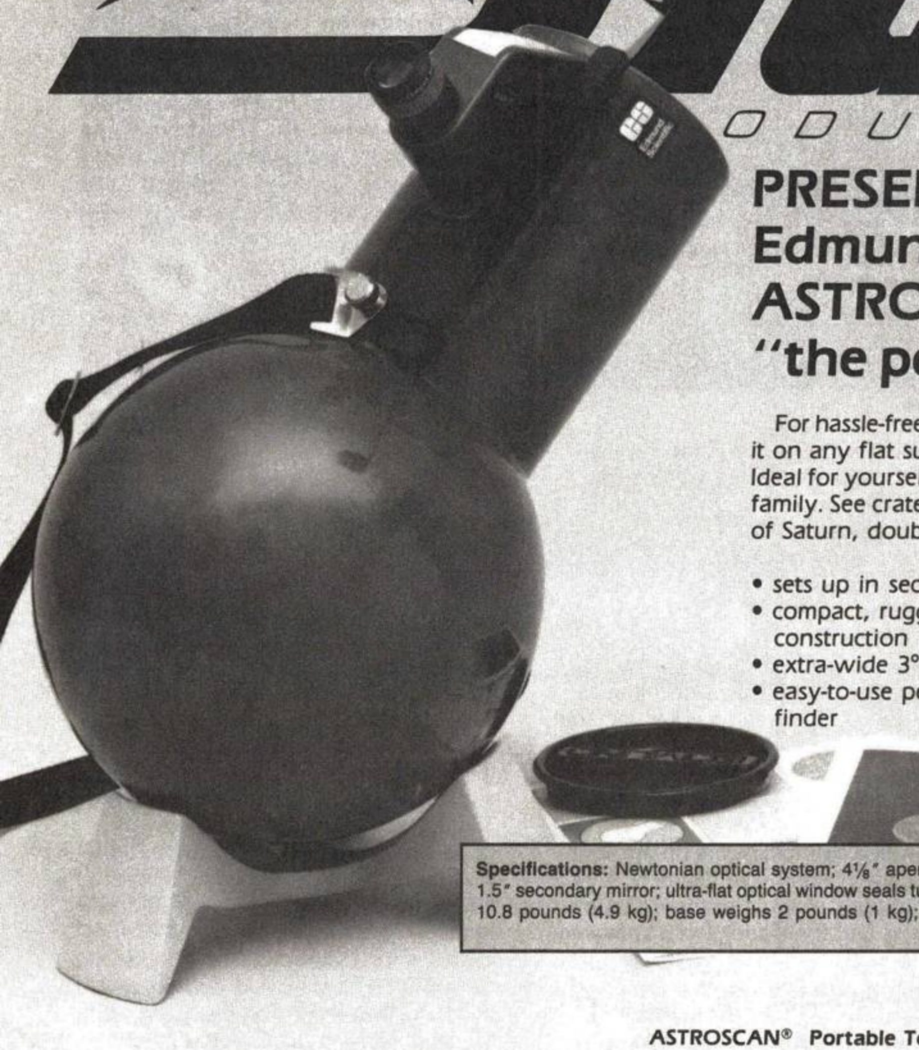

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The Texas Star Party in full swing. Alan Goldstein

on adapting roll film to commercial Schmidt cameras. And Mike Jones from Fort Worth described his tinkerings with a plexiglass all-sky mirror.

After the talks I wandered up the hill and met Ed Boutwell from Birmingham, Alabama, who showed me the observatory he built on the summit high above the ranch. Ed constructed a beautiful little dome, placed a 16-inch reflector inside, and plans on offering use of the facility for a small fee. This idea of a "public amateur observatory" is a fantastic one, especially where the skies are so good. Dedicating the structure to Sir Edmond Halley, Ed looked ahead to a time when cooperative dark-sky telescopes will be commonplace. Certainly it's a great idea.

That night Jesse Eichenlaub presented a show on the Amateur Space Telescope, through which backyard astronomers can "hook up to space" by getting some relatively inexpensive electronics and a CRT. Watch for more information on this project in coming issues of ASTRONOMY; this idea is one in which we all can participate.

Outside once again, the wind kicked up with tremendous force — we found out that a tornado grazed Midland — and blew dust, books, telescope parts, and pieces of plastic everywhere. The chances for observing looked grim, so I walked around and talked to as many people as I could about observing, amateur conventions, and various astronomical magazines. By the time I became tired it had cleared up a little, but tomorrow was the last day of the convention. I found my sleeping bag and promptly used it.

When I awoke on Saturday, I felt kind of sad. It was the last day of the second Texas Star Party: tomorrow I would make the tiring trek back to Wisconsin, and — because of talks, meeting people, picture-taking, etc. — I hadn't *really* relaxed all week. Today I had no objectives but to enjoy the people and the stars. When I walked into the conference room, the southwest region of the Astronomical League had just finished deciding to elect new officers and to hold the star party at the same ranch next year. When it comes to dark skies, astronomers don't tamper with near perfection, you see.

It was a day for papers on amateur telescope making. We heard descriptions of some of the exciting designs and innovations that appeared at the party. The most intriguing telescope was Lee Cain's entry, Houston-built 13.1-inch matched Dobsonian-mounted binoculars. This telescope was a joy to use, and offered the most relaxing views of deep-sky objects I've ever seen. Even delicately faint galaxies seemed to "float," suspended in a colorful field of view. This and other TSP telescopes will be described in detail in TELESCOPE MAKING #20.

Steve Coe of Phoenix spoke on Dobsonian construction tips, displaying his own rock-steady 17.5-incher as an example. Sherman Schultz of Macalester College in Saint Paul, Minnesota, described a 36-inch segmented Pyrex mirror he is working on, and received awards for three telescopes: a 16-inch f/12 Cassegrain, an 8-inch f/10 refractor, and a 12.5-inch f/4 Dobsonian. Other award winners included Gil Machin from Kansas City for his 17.5-inch f/4.5 Dobsonian, Kevin Medlock of California for a 6-inch f/15 refractor, David Levy of Tucson for a 4-inch f/15 talking refractor named "Mintaka," and Randy Albaugh of Irving, Texas, for a tangent arm assembly for his Schmidt-Cassegrain scope.

Wandering around looking at telescopes chewed up the entire afternoon. It was now time for dinner; Scotty Houston, his wife Miriam, a few others, and I went out for one last meal. Miriam Houston reached her 70th birthday on Thursday, and we wanted to treat her in style. Instead of the dorm-quality food at the camp, we took the Houstons for some good-and-hot Mexican food at a nearby state park. After reminiscing about the old days, we whisked the Houstons back to camp just in time for Scotty's "Twilight Talk," in which he proved that he is a born storyteller. The audience stood up and cheered for this legendary figure in amateur astronomy, whose talk provided the climactic point of the convention.

Now that the gathering was really over, it was time for one final, unabashed, stay-up-all-night observing session. The skies were very dark, and lots of meteors shot down from above; I carefully looked at many faint objects, testing the sky's transparency and seeing. I remember that I saw two 16th magnitude quasars in a 16-inch scope and that Barnard's Galaxy in Sagittarius and the faint supernova remnant NGC-6888 in Cygnus were easy binocular targets. Early in the morning, shortly before I fell asleep, the North America Nebula looked like a greenish ghostly painting in the 8 x 35s. I grudgingly acknowledged that I'd taken my last view for now in these great skies, but was consoled by the thought of next year's TSP, scheduled for May 30 through June 3, 1984.

I fell asleep about 4:30 a.m., so in the morning I barely had time for goodbyes before driving the Toyota to Midland Airport. Later, as the DC-10 taxied out on the Dallas runway bound for Chicago, I read some old copies of the *Review of Popular Astronomy* that I had picked up. And I finally had some time to think about the history of amateur astronomy. Why do people come hundreds of miles for a few days of getting together to observe? The answer is simple. In the words of Scotty Houston, amateur astronomers are *poets*. We buy telescopes and magazines and atlases and plane tickets to dark skies because — apart from the intellectual stimulation — it is so spiritually satisfying to observe nature around us and to discuss this with other humans. Yes, that's it, I said to myself. It's the best medicine in the world. I haven't felt this charged up about astronomy for a long time, I thought. And I'll bet the other 399 people thought exactly the same thing.

David J. Eicher

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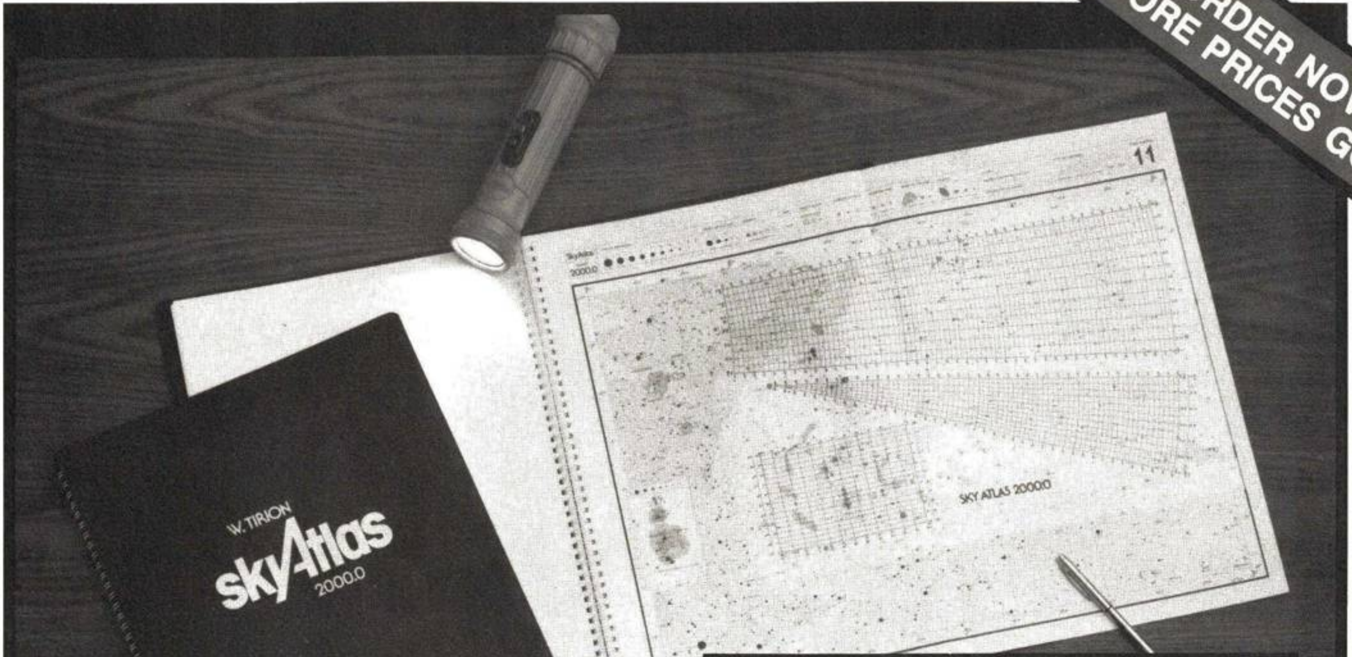

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REVIEWS

Observing Earth Satellites
Desmond King-Hele
184 pages, hardcover, $16.50
Van Nostrand Reinhold (1983)

One of the most interesting things about public star parties is the excitement that builds when someone suddenly sights a moving light in the sky. The light may be a meteor or only a high-flying aircraft, but very often it is a satellite shining in sunlight above the darkened Earth. Non-observers are often surprised that it is possible to see artificial satellites with the unaided eye, but such sightings are nothing new to regular sky-watchers.

Satellites are no longer the great attraction for backyard astronomers they once were. The heyday came (and went) in the late 1950s and early 60s, when it was fine sport to watch bright satellites (such as the gigantic Echo balloons) as they glided through familiar constellations on their regularly scheduled passages. Older readers may remember the Moonwatch teams and the almost nightly bulletins from the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts.

But for some observers, the excitement never waned. And it is for this latter group — as well as for general observers who want to pick up a new challenge — that Desmond King-Hele has written his book.

The first three chapters deal with background material on satellites: how they are launched, how they stay in orbit, and why some fall back to Earth. The author also discusses specific satellites and their missions. His last five chapters explain satellite tracking with photography, radar, and lasers. Included here are reasons why observing satellites is important. King-Hele describes work that is done to determine the Earth's exact shape and even to track the winds using data on satellite orbits.

But his middle three chapters, which total just 63 pages, will interest active observers most. This is where King-Hele describes the actual process of observing satellites. He does it in sufficient detail and with enough humor to keep the reader's interest: "To make your observation, you need to go out, wearing a digital wrist watch (and clothes if you wish, but that's not essential), about three minutes before the predicted time, which may be in error by a minute or two."

The book is well illustrated with photos and charts to help you determine such things as the period of a satellite if you know its height, the ground distance of the satellite given its known height and observed angular altitude, and so on. The author tells you how to estimate a satellite's position with reference stars, how to plot it on a chart, how to estimate magnitude, and how to make accurate timings. Numerous examples serve well to illustrate the principles involved and to lead the satellite-watcher to more precise observations.

Observing Earth Satellites is logically organized, well-written and peppered with just the right amount of dry British humor. King-Hele is a veteran satellite watcher with more than 8,000 observations to his credit.

He has provided a basic and valuable introduction to making satellite observations from Great Britain. However — there's a flaw in the book for North American observers. Official predictions of satellite passages, on which *Observing Earth Satellites* relies heavily, are no longer published regularly over here as they still are in Britain and in some other countries. In order to make any observations of *scientific* value, you must first identify the satellite and have a reasonable idea of when to look for it. Thereafter an observer can make his own predictions. But without the initial identification of the satellite, the observer's efforts can contribute little to science.

The fault here lies not with the author, but with the government funding cuts that have canceled the regular publication of satellite predictions in the United States. Some organizations, such as the British Astronomical Association, will provide predictions to observers — but generally speaking, you must first prove your worth by making accurate observations before receiving any predictions. It's the old story of "you need experience to get a job, but you need a job to get the experience."

This is less of a drawback than it might seem. Even without satellite predictions, observing and making approximate predictions on your own are certainly enjoyable, even if you don't know what satellite it is you're observing. Perhaps the greatest drawback in the book is that King-Hele only superficially addresses this possibility.

Observing Earth Satellites is still a valuable book to anyone who can obtain satellite predictions. But everyone else would do well to look the book over in the library before investing his cash. *Larry Sessions.*

Kepler
John Banville
197 pages, hardcover, $13.95
David R. Godine (1983)

Kepler is a biography in the form of a novel about the life of Johannes Kepler, the German Renaissance astronomer whose three laws of planetary motion led directly to Newton's more precise formulations, and whose work helped establish modern astronomy. This is the second of Banville's astronomical novel-biographies; the first was *Doctor Copernicus*, published in 1976.

Highlights of Astronomy
R.M. West, ed.
817 pages, hardcover, $93.50; paperback, $43.50
Reidel (1983)

This book contains about 100 of the talks presented at the International Astronomical Society's 18th general assembly, held in Patras, Greece, in August 1982. Invited review talks include discussions on modern cosmology by

Soviet astronomer Ya. B. Zeldovich and the origin and early history of the solar system by George Herbig of Lick Observatory.

Along with the four invited talks, the volume includes proceedings from seven Joint Discussions — "Mini-Symposia" — that lasted an entire day. They include papers on variations in the Sun's luminosity, the extragalactic distance scale, active galactic nuclei, and mass loss phenomena.

The Joy of 'Gazing
David H. Levy
67 pages, paperback, $3.50 (Canadian)
Royal Astronomical Society of Canada, Montreal Centre (1982)
[publisher's address: Box 1752, Station B, Montreal, Quebec H3B 3L3]

Subtitled "A Personal Guide for a New Observer," this booklet contains useful introductory hints on observing a wide range of sky objects, including comets, asteroids, planets, the Sun and Moon, variable stars, and deep-sky objects. The author writes in a relaxed, friendly way, and suggests many practical tips from the experiences of a long-time amateur astronomer. This volume will be refreshing reading for budding stargazers and probably for experienced ones, as well. *David J. Eicher.*

100 Billion Suns
Rudolf Kippenhahn
264 pages, hardcover, $25
Basic Books (1983)

Kippenhahn, a German astronomer, tells the story of stellar evolution for the general reader. Since the subject covers his own professional work, he illustrates a number of points with anecdotes that reveal a lot about how the work of astronomy actually gets done.

Cataclysmic Variables and Related Objects
Mario Livio and Giora Shaviv, eds.
351 pages, hardcover, $48
Reidel (1983)

Astronomers believe that cataclysmic variables are low-mass, very close binary systems in which material rich in hydrogen flows into the rapidly rotating accretion disk around a hot, dense primary. They are responsible for all nova explosions. Unfortunately, astronomers accurately know only one physical property of many cataclysmic variables — their orbital period.

This book contains the proceedings of the first colloquium explicitly devoted to cataclysmic variables. Topics include X-ray, optical, and radio emission, nova outbursts, and evolution of cataclysmic variables.

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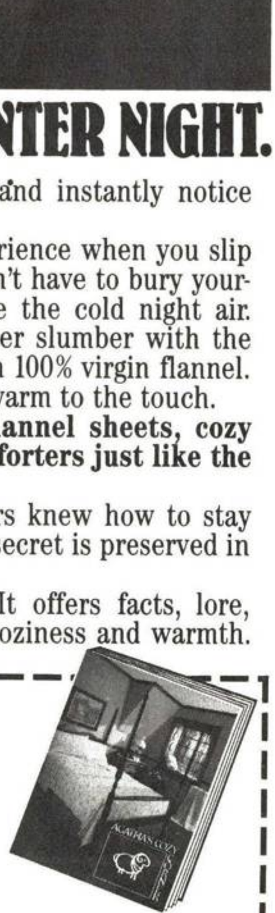

A Starhopper's Guide to Messier Objects
Lenore Freeman
23 pages, softcover, $6.95
Everything in the Universe (1983)

A Starhopper's Guide to Messier Objects really does contain just one page of text explaining the starhopping technique. All 110 Messier objects are covered in the constellation diagrams. A chart at the end of the book lists each object's NGC designation, right ascension and declination, type, magnitude, visibility, apparent and true diameter, and distance. The book also contains simple "locator" charts for the constellations of the north circumpolar and equatorial regions.

A Starhopper's Guide to Messier Objects is a good book for beginners, though it does assume that the user is already familiar with the Messier catalog. One drawback: The book is printed on very flimsy paper, causing a considerable amount of show-through in the diagrams. *Nancy Mack*.

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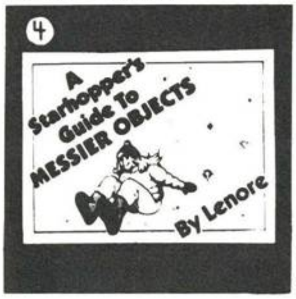
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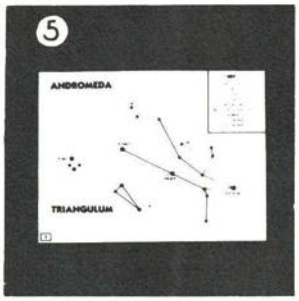

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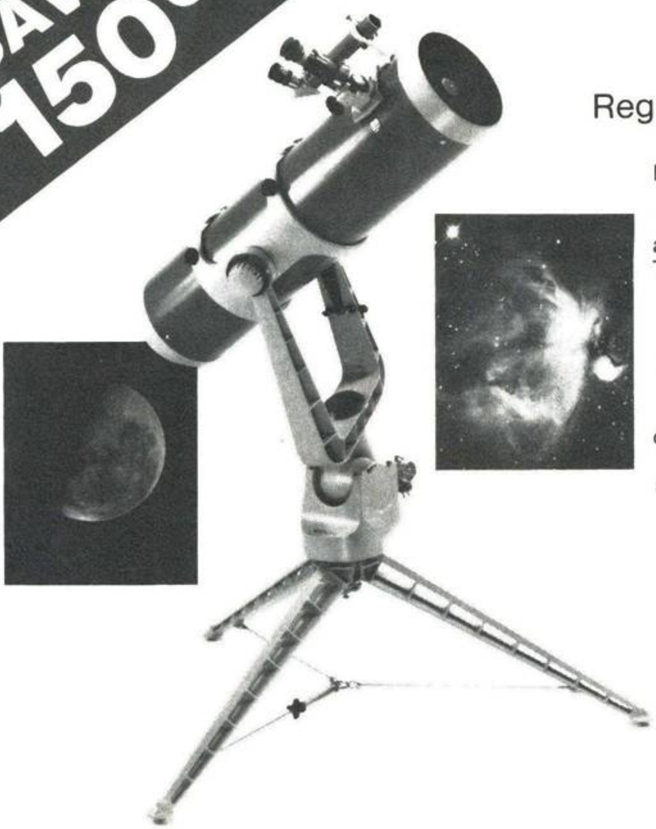

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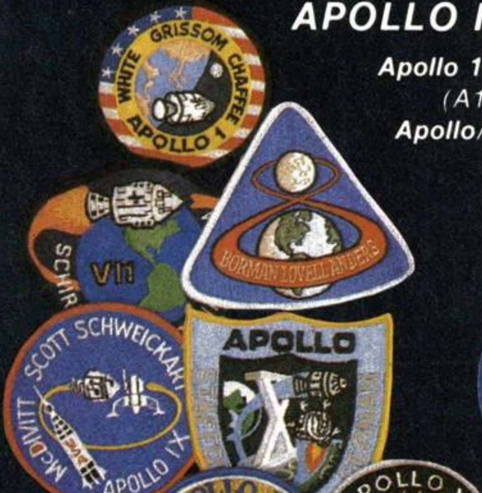

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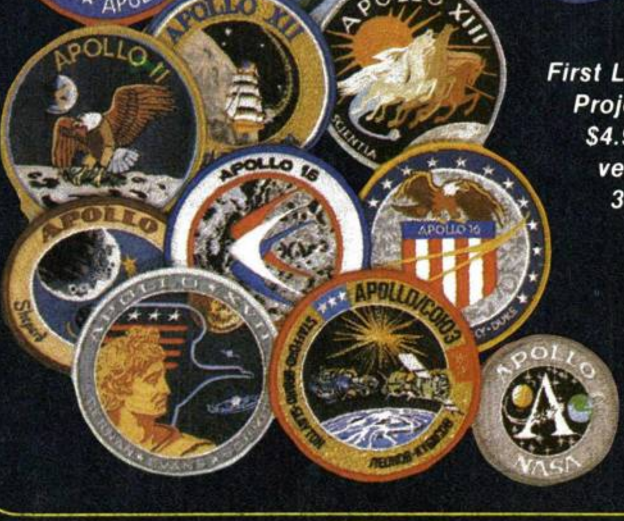

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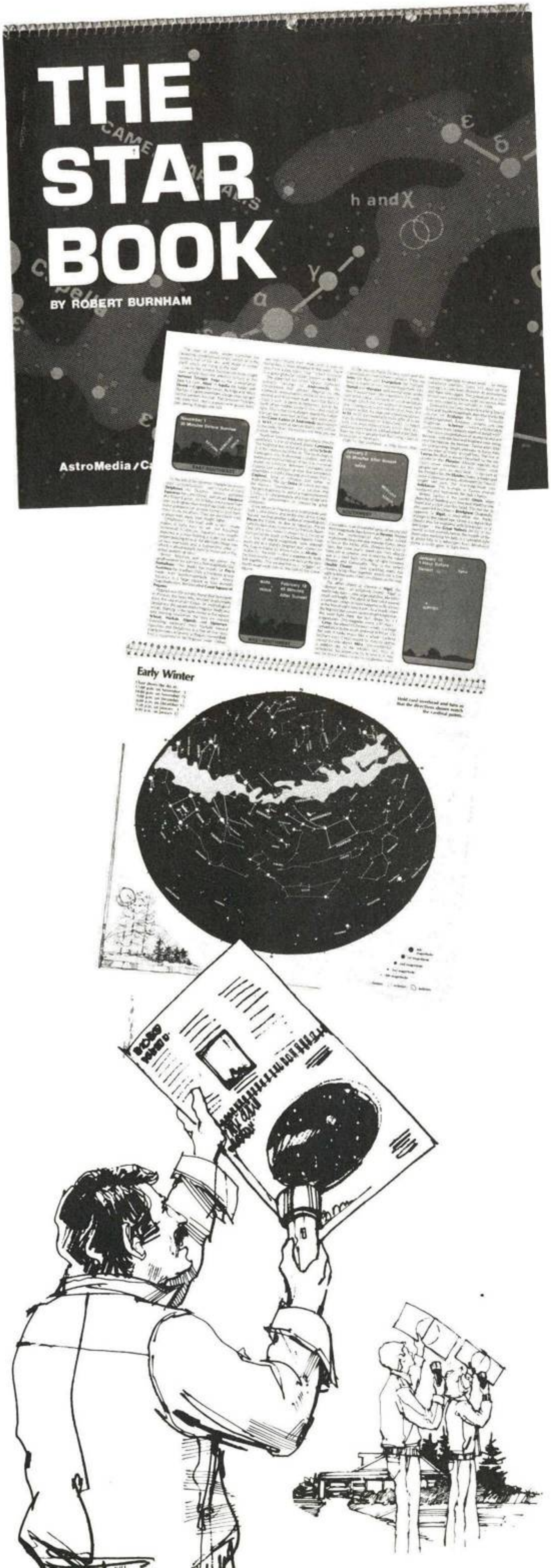

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M-42 in Color!

Sir / The color of the Orion Nebula has been a bone of contention in amateur circles for years, as evidenced by your editorial in the March issue. Many photographs by amateurs show it in gaudy reds, pinks, purples, and blues, while color composite photographs and direct views in fairly large telescopes, as you remarked, show it a pale green color. Which is correct? Fortunately, this can be answered, not by mere personal opinion, but by application of well-developed colorimetric and optical principles to the known nature of the visible radiation of the nebula.

Most of the light of the nebula is produced by spectral line emission. I am using the data on the intensities of the strongest lines versus wavelength from the 1973 edition of C.W. Allen's *Astrophysical Quantities* (London: Athlone Press), p. 256 and p. 126 (atmospheric transmission). A straightforward chromaticity computation reveals the dominant wavelength of this spectral distribution (when observed at 45° altitude) to be 502 nanometers and the hue purity to be 18%, referred to color seen under daylight illumination. This is a slightly bluish, pale green.

Physiologically, the strong red Hα hydrogen line combines with the green doubly-ionized oxygen line to produce a pale greenish yellow, which in turn combines with the blue-green oxygen and Hβ hydrogen lines to give a pale green. The weaker lines basically reinforce this mixture. Even if there is a weak nebular continuum due to dust-scattered light of the Trapezium and other embedded luminous stars, its only significant effect can be to desaturate or weaken the color due to emission. However, there is more to predicting the actually observable color of the nebula.

The average luminance of the nebula is approximately 3x10^{-7} stilb, less than a thousandth of the lower limit for normal color perception. Knots and streamers ten times more luminous than the average, viewed in 4- and 12-inch telescopes at 100x, are seen at the astonishingly low luminances of 4x10^{-9} and 4x10^{-8} sb, respectively. It is fair to ask whether the predicted color can be seen at all.

Yes, in the larger telescope, but with the green appearing as a more yellowish hue (the Bezold-Brucke effect). The mixture color perception threshold for large extended sources has not been well determined from laboratory experiments; but pure yellow can just be seen in sources subtending 3° to 9° at luminances of 3x10^{-8} to 3x10^{-9} sb. Green requires 2 to 3 times, and medium red (Hα) 12 times more luminance, respectively, than yellow to be seen.

We therefore estimate the threshold for the mixture green in question at approximately 2x10^{-8} sb for knots and streamers covering a 5° angle in the magnified image. At higher magnification the color persists because the threshold decreases. The natural sky background, with a color temperature of 5,600° K, has no significant effect on the observed color, although an artificially light-polluted sky could. In Santa Monica, where the best sky is six times brighter than natural, I see a distinct pale green in the Orion Nebula with a 12-inch telescope but only the weakest hint of color in an 8-inch.

What about the gaudy photographic colors? The spectral response of color films to the solar spectrum are very different from the human eye's. Wavelengths as short as 570 nm (which appear yellow to the eye) are recorded as red, and there is no appreciable discrimination between orange, orange-red, and the pure reds. Kodacolor records yellow as greenish-yellow and discriminates poorly between green, blue-green, and blue; it records blue either purplish or too bright, depending on exposure time.

Ektachrome fails to respond to the wavelength of the green line in the Orion Nebula at all in exposures showing yellow and orange (much like a human with green-defective red-green color blindness) and records all blues as a deep sky-blue. If it is exposed enough to show green, yellows vanish and the blues become a uniform blue-violet. No wonder the photos of the Orion Nebula are so often reddish, purplish, or pinkish!

While it might be argued that the greenish hue seen in medium and large-aperture amateur telescopes is abnormally perceived due to its low luminance, amateur astronomers should be aware that the colors recorded on commercial color films are a poor standard of comparison.

Philip C. Steffey
Santa Monica, CA

Military Welfare

Sir / Allow me to point out that Congress is only authorized by the Constitution to spend money for "the common defense and *general* welfare." (My emphasis.) Your editorial stance is to berate the expense of the military while ignoring, indeed sometimes approving, the increase in spending for welfare programs, many of which Congress is probably not authorized to spend money for because they are arguably directed towards special interests.

It should also be noted that the success of our space program owes a great deal to the military, from which much of its early hardware, all of its early astronauts and pilots, and most of its technological expertise are derived. The relationship between the military and NASA is symbiotic at worst — NASA is an offshoot of the military, not the other way around. In competition for funds between NASA, the military, and social spending, NASA will almost always lose. At least under the auspices of the military, space will not be totally ignored. Of course you will argue that such a situation would be space exploitation, not space exploration. However, it is better to be active in space in some capacity rather than not be in space at all.

The article that prompted me to make the above comments was your article on the Ariane rocket (Forum, April 1983). In the article Donald Robertson states, "Political and military requirements for locating the national space port within national boundaries took precedence over economies of operation — a good example of the kind of thinking that is ruining the Space Shuttle's chances for commercial success." What would happen if our national space port had been built in a country like Nicaragua? Today we would be a) minus one space port or b) fighting and expending lives to maintain our space port. (Never mind trying to keep it safe from sabotage and terrorist attacks.) Neither alternative is conducive to *any* space program, much less a program that is trying to be a "commercial success."

It would be refreshing to see more thoughtfulness in the content of the commentary in your magazine.

David Grenier
Providence, RI

The State of English Telescope Building

Sir / Concerning your review of James Muirden's *Amateur Astronomer's Handbook* (ASTRONOMY, July 1983): In shamefaced defence of Mr. Muirden's omissions, I'm very much afraid that the English amateur telescope scene is trailing far behind the more advanced American state of the craft.

The Dobsonian is indeed the biggest innovation in telescopes in the last 50 years, yet Mr. Muirden's failure even to mention the subject isn't difficult to explain. There simply hasn't been a "Dobsonian revolution" in England.

No large Dobsonians are available commercially, nor are there reasonably priced, large-diameter thin mirrors with which to build one. At best, Dobsonian technology is used by only a handful of the better informed amateur astronomers to mount *small*-diameter, commercially purchased optics.

As a result there has been no consequent "aperture explosion" — in England there are very few large-aperture telescopes. The local astronomical society that can boast of a 12-inch for the use of its members is still a club to be envied. And the individual with a 10 or 12-inch is a very rare bird, held in great esteem. The majority of English observers are still using 4-inch to 8-inch commercially produced instruments. Amateur mirror making and telescope construction are fairly unusual — and generally restricted to what an American enthusiast would consider very small fry.

As an English mirror-maker who has successfully ground large thin mirrors and constructed Dobsonians, I find the British reluctance to follow such a good American example baffling and frustrating. I have even advertised to build Dobsonians to order. The result? One inquiry only, which requested me to explain just what on Earth a Dobsonian telescope was!

It seems clear to me that the state of telescope making in England more than explains Mr. Muirden's omissions. Our mirror-makers and telescope builders are thoroughly stuck in the mud, a decade or so behind their American counterparts.

Brian Slade, F.R.A.S.
Sheppey, England

Where Are We?

Sir / From time to time you mention that our solar system is passing through our arm of the Galaxy and will eventually emerge from it into the space between the arms. If this is so, any ideas as to why our solar system is apparently not part of the spiral arm?

Grant Telfer
Monash, South Australia

— The Sun is located on the inner edge of a spur in the Orion arm of the Milky Way. Spiral arms are defined by the young, massive blue stars they contain. These massive suns generally do not live long enough to drift out of the spiral arms in which they formed. Low-mass stars like the Sun, however, live long enough to complete many trips around the Galaxy. The solar system has completed at least 20 circuits of the Milky Way over the last five billion years. For more information, see "To Sculpt the Galaxies" — in our January 1983 issue.

behind the scenes

those dull fall skies

October is one of the finest months for observing, at least here in Milwaukee. The air is cool and crisp (doubly comfortable because summer's mosquitoes have succumbed to the frost), and nights are often clear and dark. And they begin early, too. But the bright planets have deserted the sky, the rich starfields of the southern summer Milky Way have sunk into the west, and the brilliant stars of winter don't rise until the wee hours — so what's to observe?

Of course, you immediately think of the northern reaches of the Milky Way — the clusters and nebulae of Cygnus, Cepheus, Cassiopeia, and Perseus — but south of the zenith the sky seems blank and dull. Just naming the constellations is enough to make your heart sink: Capricornus, Aquarius, Pisces, Cetus — big, "dull" regions with no bright stars.

Well, maybe it's time for a galaxy hunt! Those big, star-poor constellations are picture windows in our Galaxy looking out into the depths of space. Who needs spring's Virgo Cluster when you can scan the galaxies of Cetus? (Don't forget M-31 and M-33, either!)

If you live in the city as I do, it means a night or two of camping away from city lights. The parks and campgrounds are uncrowded at this time of year, so you probably won't suffer somebody's Coleman lantern or someone else's loud all-night rock music. The air is likely to be bracing, rather than frigid; dressed in heavy winter clothing, you'll easily stay warm all night. Take along your copy of this month's ASTRONOMY with Alan Goldstein's "Observing the Autumn Galaxies," your trusty star atlas and telescope, plus oatmeal raisin cookies and lots of hot chocolate in a big thermos. To cap it all off, of course, you'll get to see Orion as it rises before dawn.

If you don't have a telescope yet, you can always spend the night learning all those big, "dull" constellations by heart and perusing the Milky Way with binoculars, getting ready for the day you'll take the plunge — for which we recommend our biannual "Buyer's Guide to Telescopes." Just in time for the holiday season, too. As we have before, once again we recommend that you start off with a modest telescope and work up from there to the "big stuff." If you want to read about how real fanatics observe, by the way, take a look at this month's Forum. It takes lots of dedication. . . .

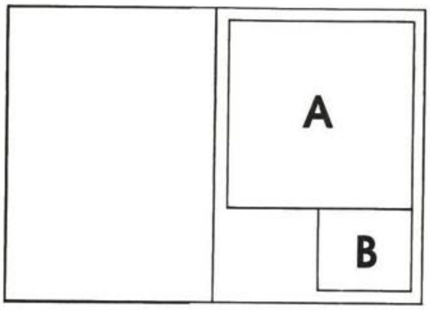
Sincerely,

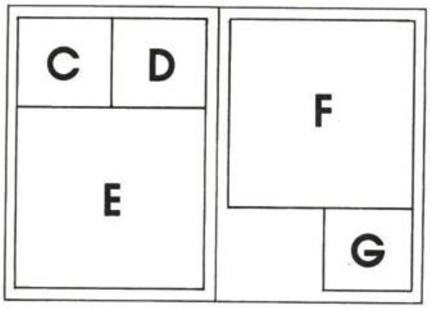
Richard Berry

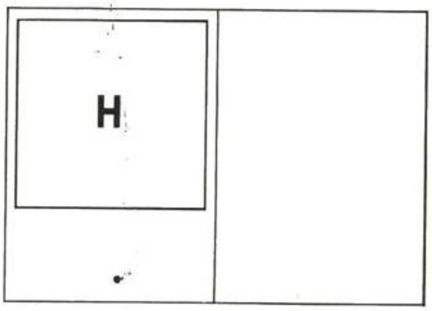
Richard Berry
Editor

photography
in
astronomy

indonesian eclipse pictorial







A. Using a 6-inch Maksutov with a focal length of 2900 mm, Jacques Guertin exposed for the middle corona. Note subtle radial "brushes" extending from the polar regions of the Sun.

B. From Tanjung Kodok, David Treganowen captured the "diamond ring" at third contact with an 800 mm f/8 Tokina lens on Kodachrome 64 slide film at $\frac{1}{125}$ second. Mr. Treganowen writes: "I had a lot of difficulty setting up . . . it was 105° in the sunshine at 9:20 a.m."

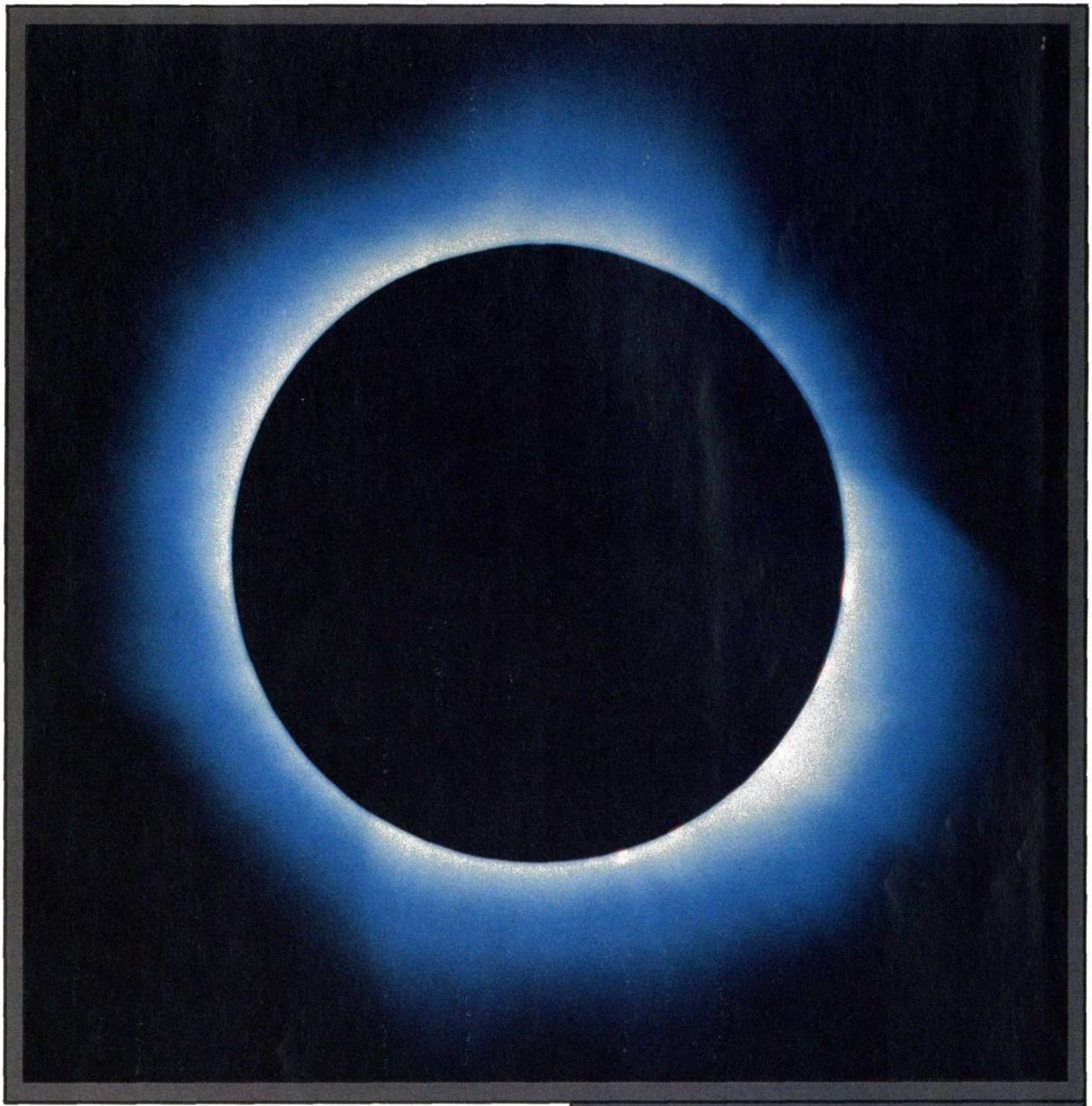
C., D. Taken seconds apart, two $\frac{1}{250}$-second exposures on Ektachrome 400 by Irv Abrams show the blinding re-emergence of the Sun from behind the Moon. Internal reflections in the optical system account for the strange pattern of light in the second picture. Mr. Abrams used a 3½-inch Maksutov telescope.

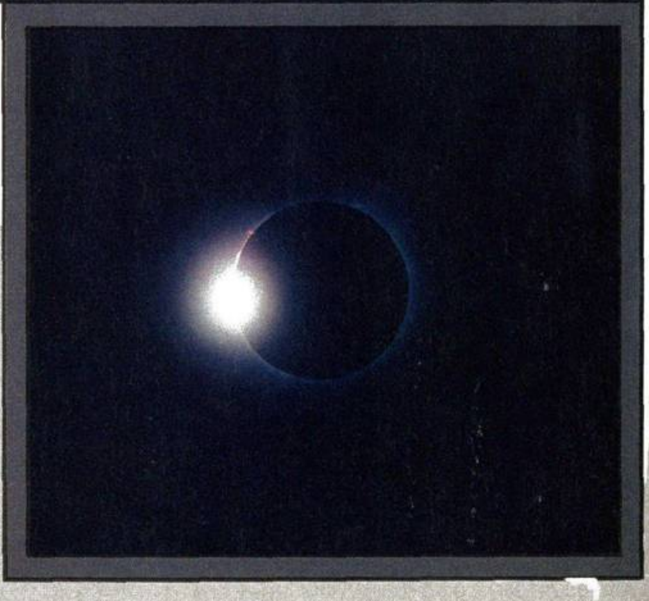
E. From Tanjung Kodok, Ronald Royer recorded the first seconds of totality. He used a 4-inch f/5 Newtonian reflector with a focal extender to enlarge the image to the equivalent of f/10. Note the cross-shaped diffraction extending from the last gleaming points of solar photosphere. These are due to the diagonal mirror supports.

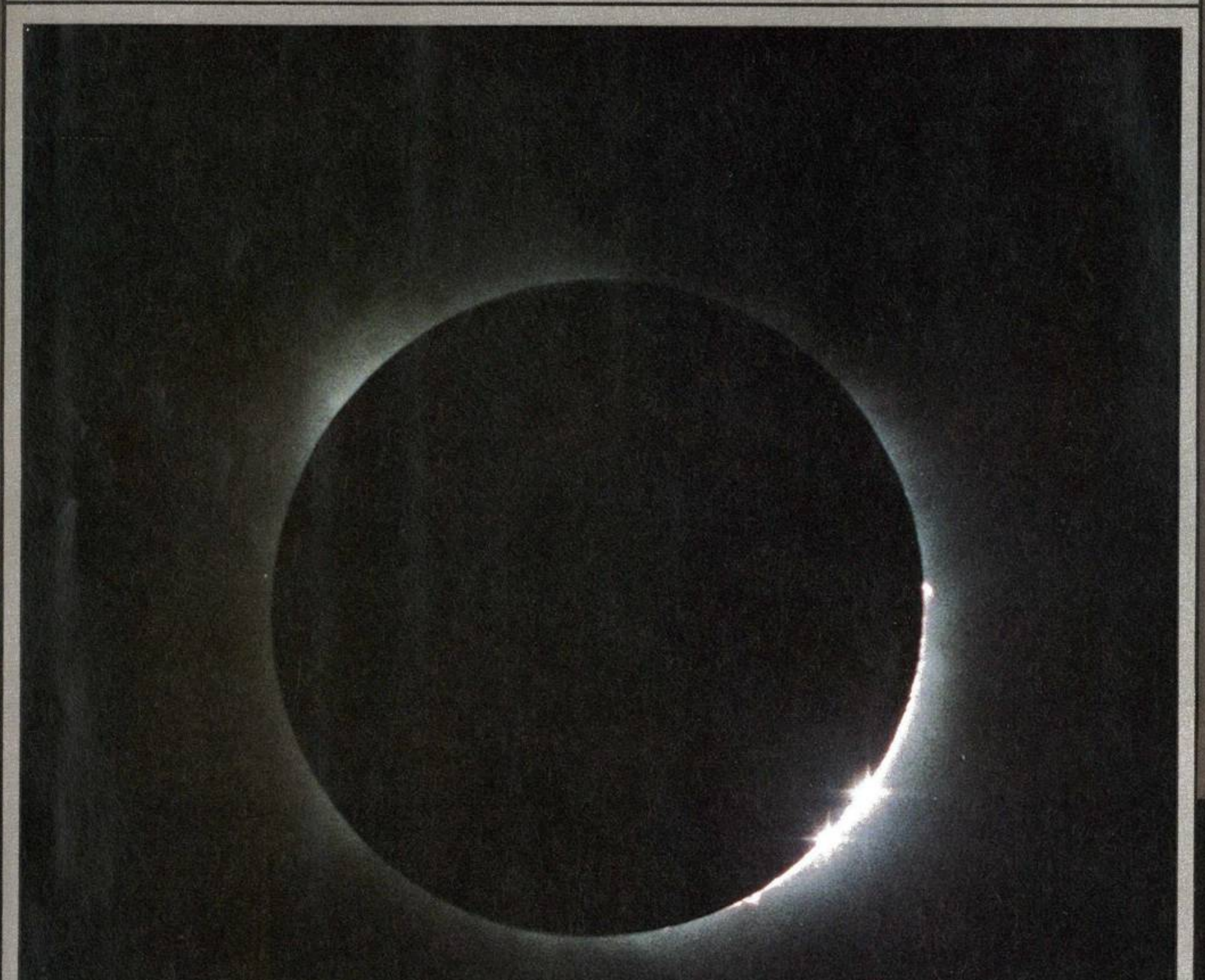
F. Khoo Chong Yee of Singapore captured the solar corona from Purworejo in central Java by pointing his 35mm camera into the eyepiece of an Astroscan telescope. Khoo used Kodak's new VR-1000 film and a $\frac{1}{60}$-second exposure. The effective focal length of his setup was 794 mm.

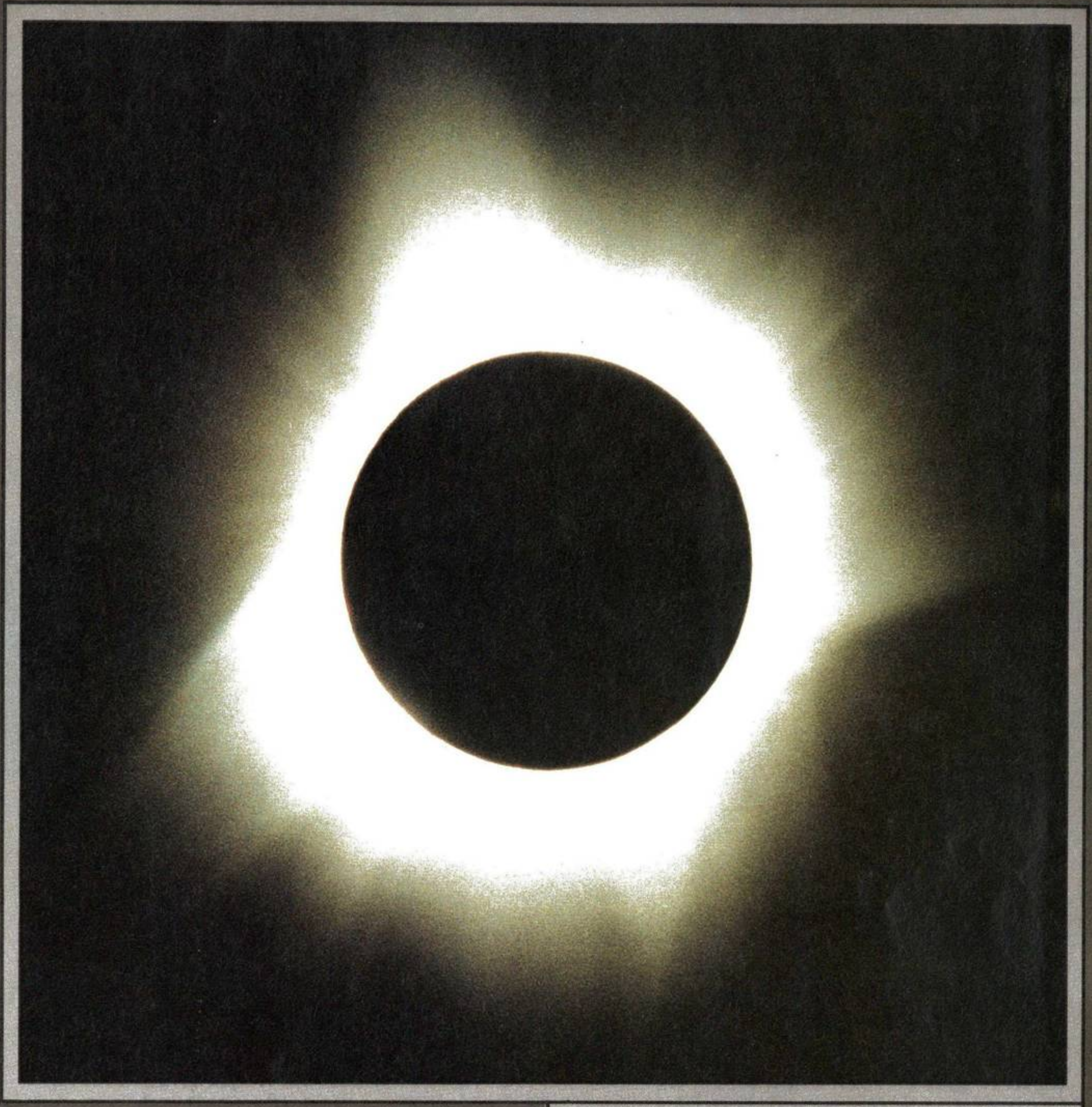
G. A one-second exposure through a small refracting telescope (aperture 68 mm, focal length 600 mm) yielded a dramatic image of outer coronal streamers. Because of light haze, the image of the Moon did not remain completely black.
Photo by C.W. Law of the Hong Kong Sky Observer's Association.

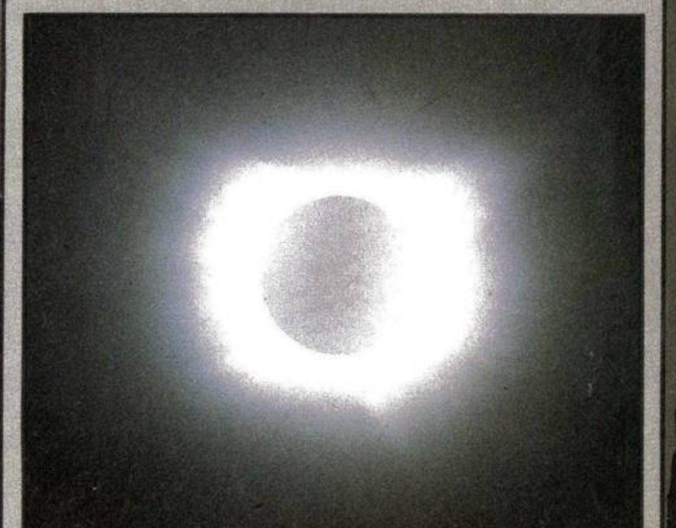
H. From perfectly clear skies a few miles south of Yogyakarta, Don Trombino, recorded the outer solar corona with a $\frac{1}{4}$-second exposure on Ektachrome 400 slide film with a 1000 mm Maksutov telephoto lens.

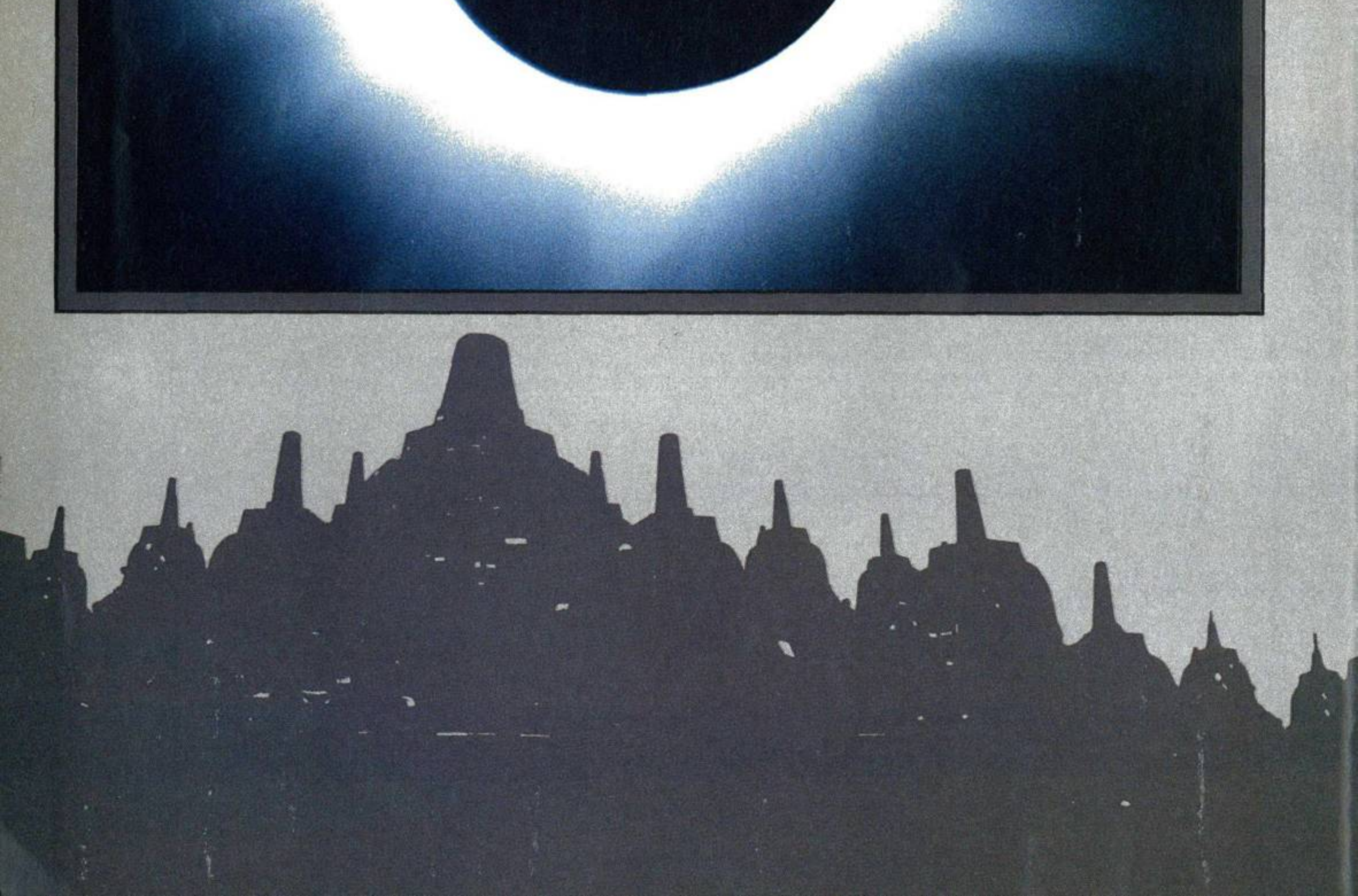












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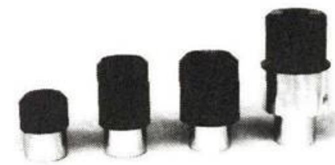

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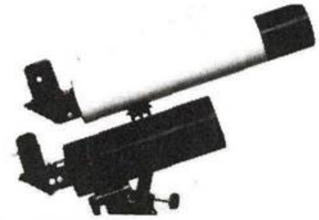

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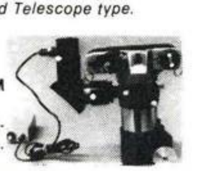

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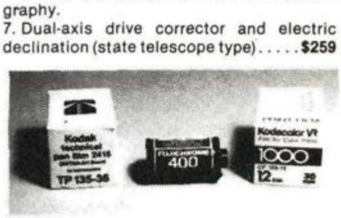

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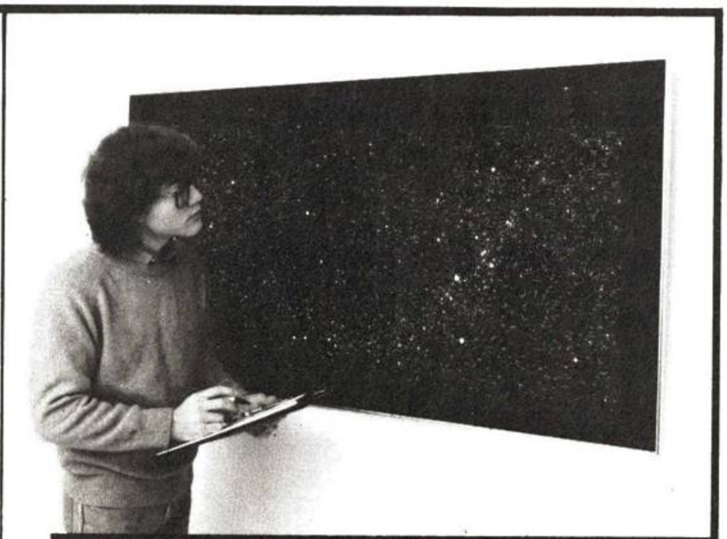

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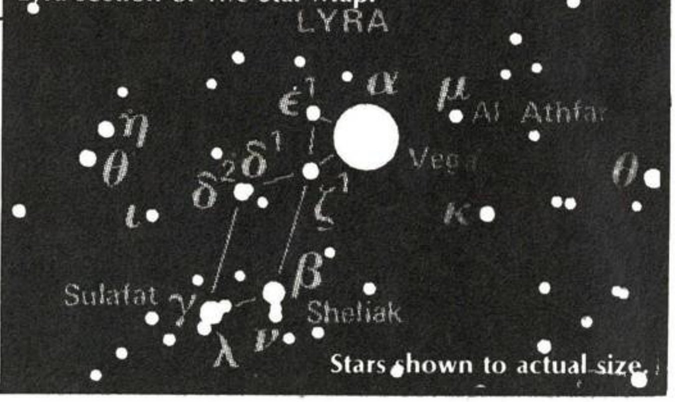

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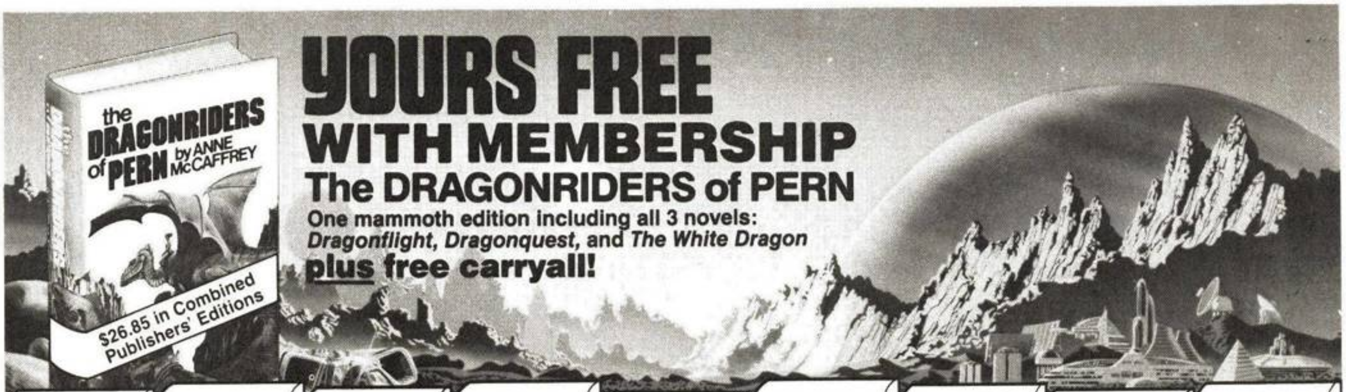
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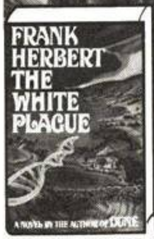
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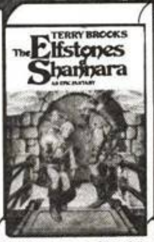
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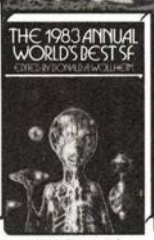
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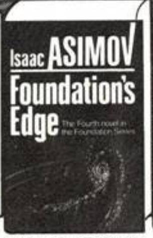
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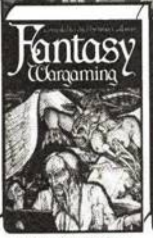
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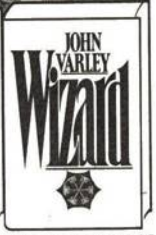
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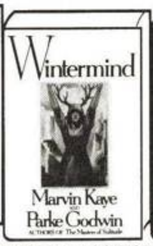
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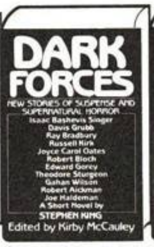
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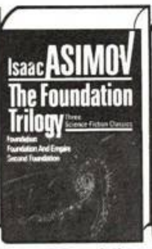
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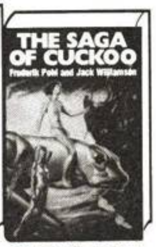
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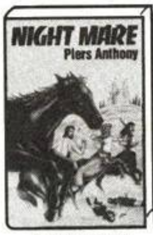
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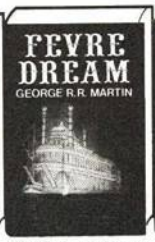
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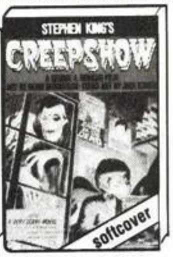
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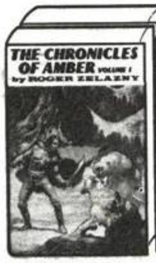
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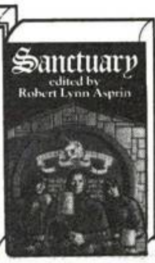
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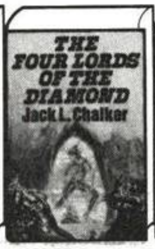
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eye on the sky

venus dominates, jupiter in conjunction

by Fred Schaaf

the wanderers

October is an exciting month for viewers of solar system bodies: although the brightest planets are still gearing up for a great pre-dawn congregation in January, they are easily visible now, if a little spread out.

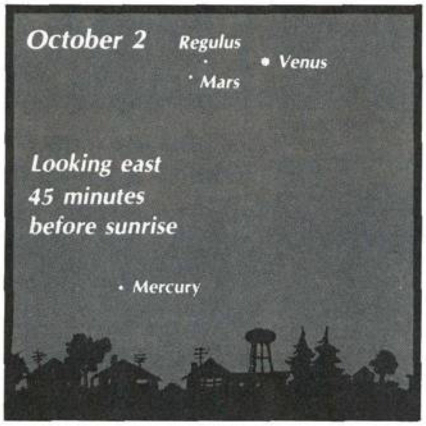
Still dominating the morning sky is **Venus**, which continues to increase its separation from the Sun. This is an ideal apparition of Venus for the United States, Great Britain and Europe — during most of the month the planet rises about three hours (and for a time almost four hours) before Sol. It's especially nice that Venus rises so high before dawn around October 1, because this is the date of Venus' greatest brilliancy, magnitude -4.27 — a bit brighter than back in July, when the "evening star" was not quite as elevated. Its altitude will peak during early November when it is near greatest elongation.

Back on September 14, Venus was almost as far south of the ecliptic as is possible, passing a full 9° south of **Mars**. Now, as Venus heads more directly away from us and its elongation decreases, Mars — creeping eastward — and the starry backdrop get a chance to "catch up" due to Earth's orbital motion. So a rather complex orbital situation results in a month of interesting arrangements of Venus, Mars, the star Regulus, and the Moon.

On the first three mornings of October, Venus is still far enough south of the ecliptic to appear at about the same altitude as the more easterly and northerly placed Mars and Regulus. Therefore, as twilight brightens, most readers should see Venus a short distance directly to the right of Regulus and Mars. While Venus is nearly at its brightest, Mars is nearly at its dimmest — its magnitude of 1.9 makes this ruddy point of light distinctly dimmer than Regulus. But on these first mornings of October, the crescent Moon adds further interest and beauty as it cruises north of Mars, Regulus, and Venus on the morning of the 3rd and then passes north of Mercury between the mornings of the 5th and 6th.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

The third planet in the morning sky is **Mercury**, which gives its best showing of the year this month. Mercury is at greatest elongation on the morning of the 1st, about three hours after Venus is at greatest brilliancy. Its small separation from the Sun — 17.9° — nevertheless brings it above the horizon almost 1½ hours before our star. Mercury is quite bright in the latter half of the month (shining at magnitude −1.0), but then will sink too low for easy visibility. The ruddy planet reaches superior conjunction on October 30, just two hours after it passes 4′ from the star Lambda (λ) Virginis. At this point they will lie less than a degree from the center of the Sun's disk.



Little Mercury is no more visible the next day — Halloween — when it passes 2° south of another planet undergoing superior conjunction, **Saturn**. The pair is then lost in the solar glare, little more than 1° from the Sun's center. During the first week of October, however, Saturn might be visible low in the southwest after sunset. What is the last day you can see it?

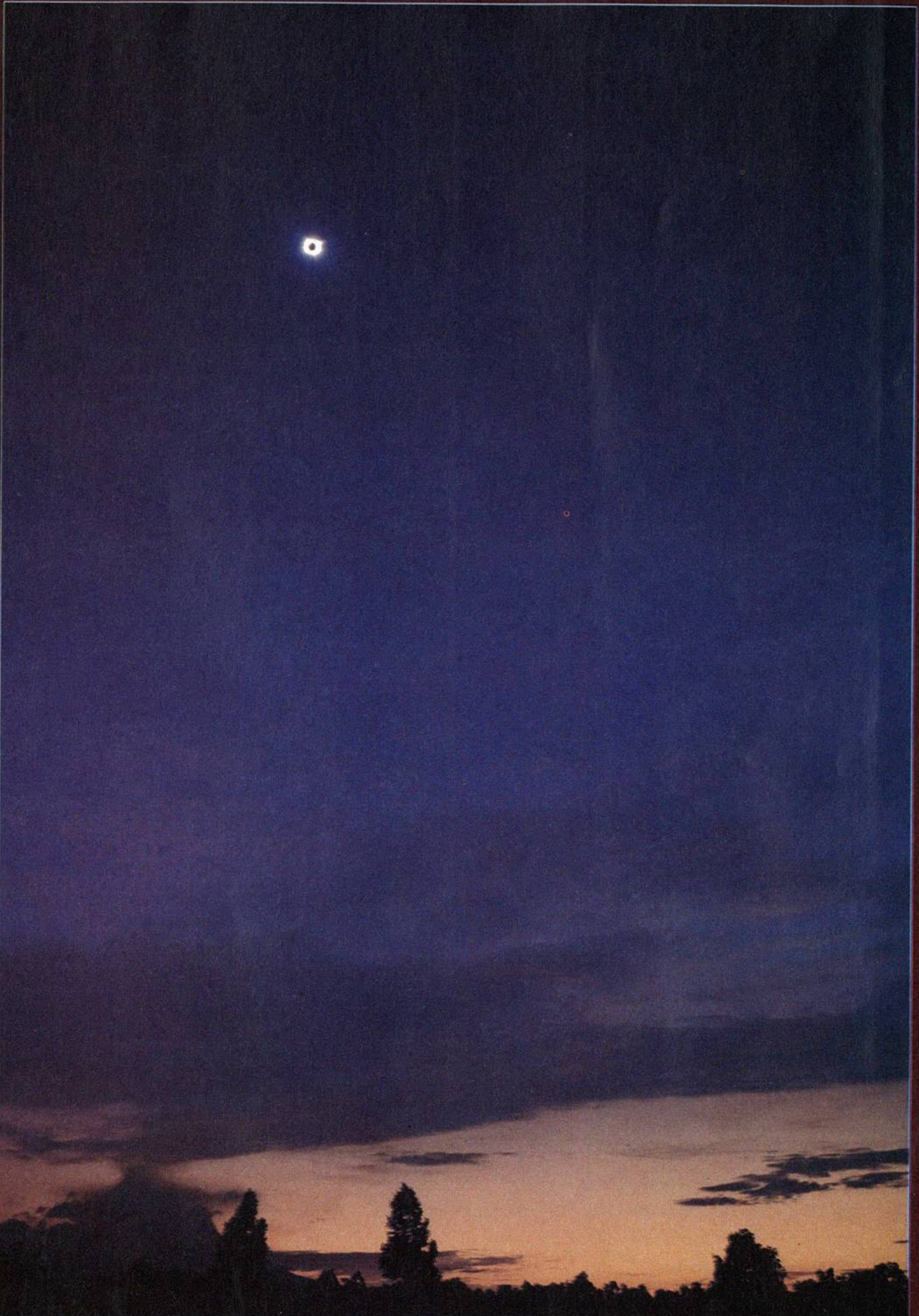
On October 3 Saturn passes 15° south of **Pluto**. Saturn/Pluto conjunctions happen at intervals of about 37 years, so the next will not occur until January 14, 2020, when the two will be a lot closer to each other — only 42′ apart. Unfortunately, the Sun will then lie only 0.6° away. At month's end both of these worlds are at their greatest distance from Earth for the year. Saturn is 10.8 astronomical units away, while Pluto lies at a distance of 30.8 astronomical units. But take heart, Saturn observers: next month it moves back into the pre-dawn sky.

During the final three weeks of the month, while Mercury and Saturn converge on the Sun, Mars and Venus draw closer to each other. Venus is 4° south of Regulus on the 7th, but drifts north toward the ecliptic and a fine conjunction with Mars. This, the third conjunction of these two planets in 1983, is probably the best. On the morning of the 28th, Venus is only 1.7° south of Mars — and the Moon comes back around for a pretty sight on Halloween morning.

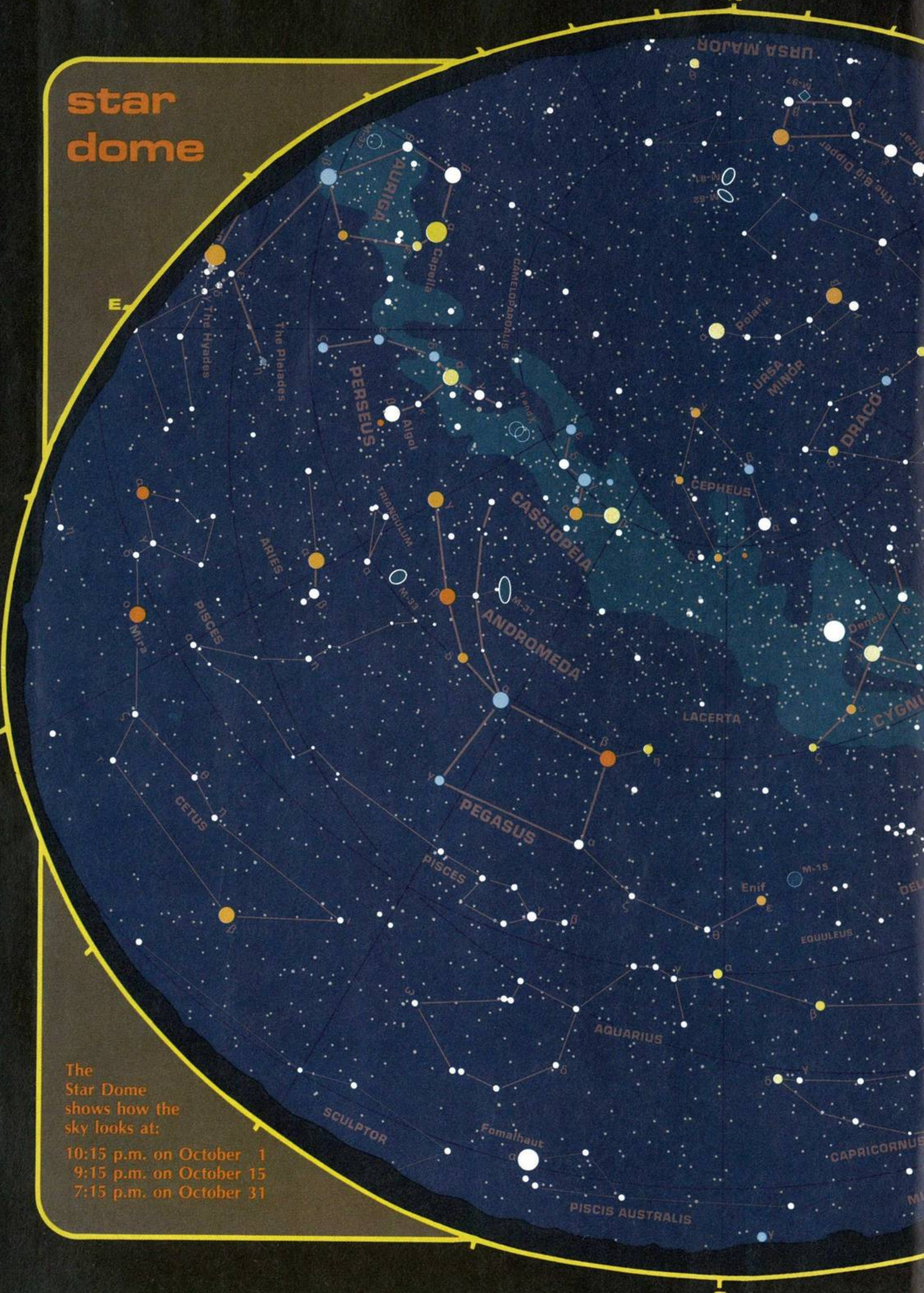
Where are the remaining planets? The other three are low in the southwest, due to switch over to the morning sky before year's end. **Uranus** and **Neptune** — being telescopic — are not very interesting, but **Jupiter** — still about as bright as Sirius — undergoes its third and final conjunction of the year with the star Antares. This takes place on the 12th, when the planet is 5° north of the star.

An even more exciting conjunction occurs on the 16th, when Jupiter closely passes the magnitude 4.6 star Omega (ω)

William P. Sterne, Jr. took this photograph of June's solar eclipse from Yogyakarta, Indonesia. Using a 47mm f/8.0 wide-angle lens and Vericolor II 4″ x 5″ sheet film, he made a 6-second exposure at f/16. Smoke belched from the Gunung Merapi Volcano rises over the trees at left.



star dome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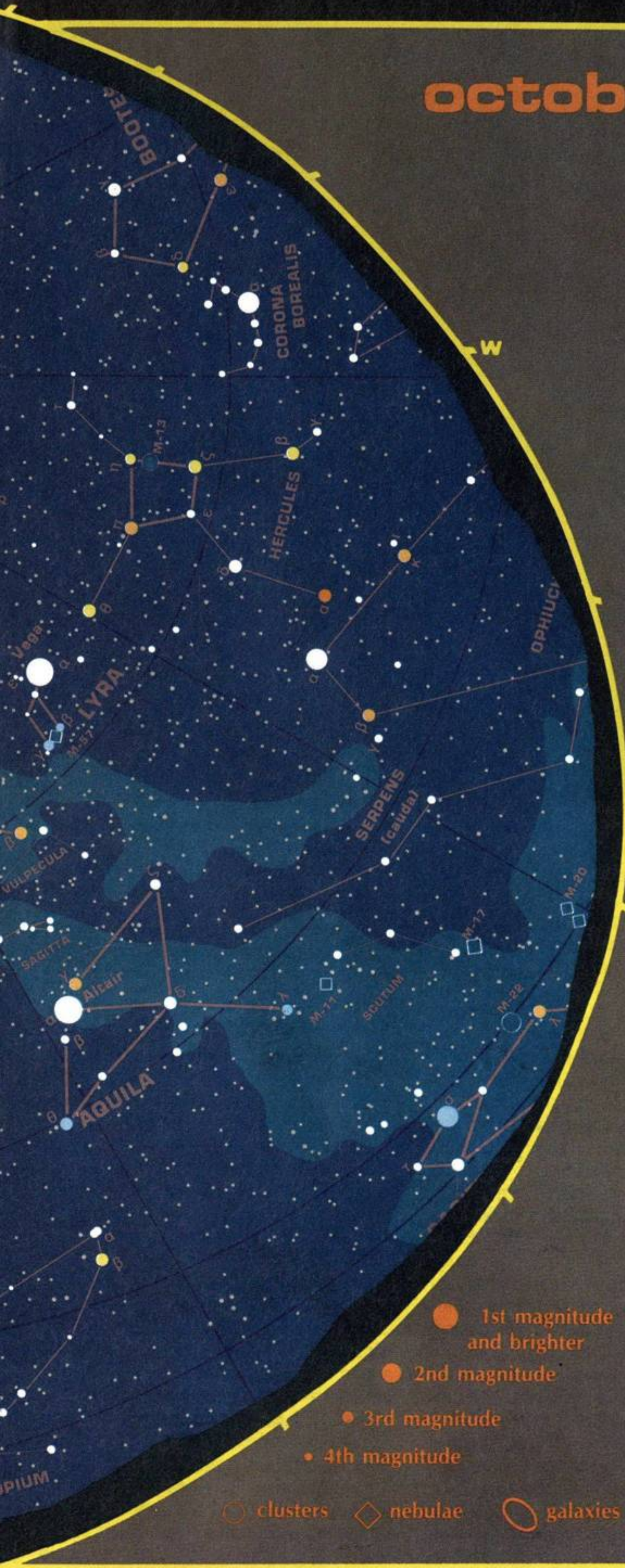
M-33
M-31
ANDROMEDA
Deneb
CYGN
PISCES
Mira
CETUS
LACERTA
PEGASUS
PISCES
M-15
Enif
EQUULEUS
DEL
AQUARIUS
SCULPTOR
Fomalhaut
CAPRICORNUS
PISCIS AUSTRALIS

The Star Dome shows how the sky looks at:

10:15 p.m. on October 1
9:15 p.m. on October 15
7:15 p.m. on October 31


W
BOOTES
CORONA BOREALIS
HERCULES
OPHIUCHUS
M-13
Vega
LYRA
M-57
SERPENS (cauda)
VULPECULA
SAGITTA
Altair
AQUILA
M-11
SCUTUM
M-17
M-20
M-22
PIUM
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

october sky almanac

1st Venus is at greatest brilliancy this morning — look for it in the eastern sky during the hour before sunrise. Mercury reaches greatest western elongation from the Sun — 18°. Look for it in the east, below and to the left of Venus. This is the year's best elongation for Mercury.

4th The Moon is at perigee at 7:16 a.m. EDT: 225,203 miles.

6th New Moon occurs at 7:16 a.m. EDT.

7th Venus passes 7° south of the first-magnitude star Regulus in Leo. This morning Mars, Regulus, and Venus all form a relatively compact group in the predawn eastern sky — good "pretty-picture" material.

10th The Draconid meteor shower reaches peak activity during the predawn hours today. From a dark-sky location, you'll probably see 10 to 20 per hour.

13th First Quarter Moon is at 3:42 p.m. EDT.

16th The Moon is at apogee at 3:53 a.m. EDT: 251,539 miles.

21st Full Moon occurs at 5:53 p.m. EDT. Also, the predawn hours this morning mark the peak of activity for the Orionid meteor shower. Unfortunately, the Moon will severely limit the number of meteors seen.

28th Look for Venus and Mars close together in the eastern sky in the hour before sunrise. After sunrise, Venus will pass 1.7° south of Mars. Also, Last Quarter Moon is at 11:37 p.m. EDT.

30th Mercury is at superior conjunction with the Sun.

31st Saturn is in conjunction with the Sun.

From Queensland, Australia, Gregg D. Thompson used a 17mm f/3.5 lens and hypered 400 ASA film to photograph star trails arcing around the Southern Celestial Pole. Visible at left are smeared images of the two Magellanic Clouds, and at right is the southern Milky Way, punctuated by the twin bright yellow streaks of Alpha (α) and Beta (β) Centauri.

Ophiuchi. Although North Americans won't be able to see the closest approach (a separation of only 1′21″ — three jovian diameters — occurs after sunrise), they can see Omega as a "fifth Galilean satellite" on the evenings of the 15th and 16th. This is, by the way, the closest conjunction between Jupiter and a naked-eye star since the planet occulted Beta (β) Scorpii in 1971. A final close conjunction for this month takes place between Mars and fourth-magnitude Chi (χ) Leonis on the morning of the 23rd.

the starry sky

In Great Britain, **Ursa Major** is known as the Plough. And as author Guy Ottewell notes, on autumn evenings the Dipper really does seem to be "ploughing" up the northern landscape. Find an unobstructed view to the north and think about this perspective: the Plough looks larger than ever when it's low. If you observe from a dark site, note that the Little Dipper now looks very much like a watering can, presumably sprinkling the northern horizon in this stellar fall planting.

While you are out observing the Dipper, consider the following question: where does the line from the Big Dipper's "pointer" stars lead after it passes the North Star? A check on a sky map or out under the stars reveals that it leads to **Cepheus** the King, now high in the north. But extended much farther, this line takes us to several of the autumn sky's most important places — down one side of its most useful asterism and straight on to the season's brightest star.

The asterism is the Great Square of **Pegasus**, which forms the torso of the famed winged horse of Greek mythology. The west side of the Great Square (actually a rectangle — it is longer in the east-west dimension) roughly continues the line from the pointers, and the line so continued brings us to the sole first-magnitude star of the autumn constellations, **Fomalhaut**.

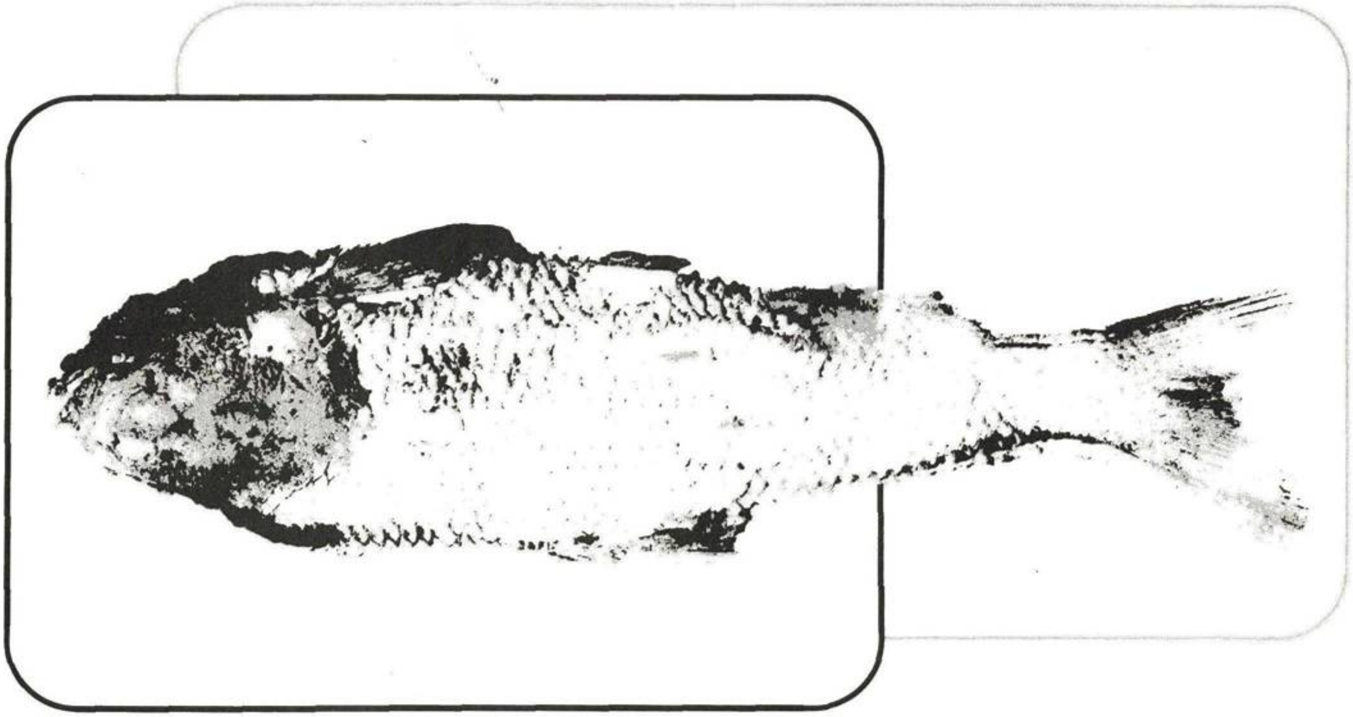
Between the west side of the Great Square and Fomalhaut are faint trickles of stars — the "streams of water" poured out by **Aquarius** the Water-bearer. The faint, sprawling constellation does this mythical star-spilling from a small asterism on the celestial equator called the Urn (or Water-jar).

Draw a line from Fomalhaut, mouth of the southern fish **Piscis Austrinus**, to the bright star at the northeast corner of the Great Square and you will find, slightly more than halfway there, a dim loop of stars somewhat larger than the Urn. This is the Circlet, just below the Great Square, which forms the head of one of the fish in the stars of **Pisces**. This fish appears to be nibbling on the celestial equator.

Just east of the Circlet is the point of vernal equinox, where the Sun lies on the first day of spring. It is also known as the "First Point of Aries" because in ancient times it lay in the constellation Aries. This is the starting point of the celestial coordinate system — just as Earth's longitude is measured from the meridian at Greenwich, England, right ascension is measured from the meridian of the vernal equinox point.

The stars of the Great Square, clockwise from the upper right, are the interesting variable **Scheat**, **Markab**, **Algenib**, and **Alpheratz**. But Alpheratz is not officially a part of the constellation Pegasus; it belongs to **Andromeda**, the chained lady of the Greek Perseus myth. Northeast from Alpheratz, Andromeda's form continues with the similarly bright stars **Mirach** and the bright double **Almach**. Note the interesting colors of these stars on the Star Dome map. Can you detect these subtle hues with your naked eye, or do you need binoculars?

Not far northwest of Mirach are two



much dimmer stars and an elongated glow of soft light visible to the naked eye. This misty patch of radiance is the amassed magnificence of hundreds of billions of suns that lie over two million light-years away: **M-31**, the Andromeda Galaxy, the largest member of our Local Group of galaxies.

North of M-31, now high in the northeast, is the bright M of **Cassiopeia** the Queen (Andromeda's mother). The line extended from Alpheratz through Mirach through Almach leads on to the brilliant grouping called **Perseus** (Andromeda's hero).

Now low in the east are winter's first bright stars: yellow **Capella** and orange **Aldebaran**. Note that for most of us, Aldebaran rises not long after Arcturus sets. Although the Summer Triangle, composed of three first-magnitude stars, is still prominent in the west, this is the time of year when we see the fewest first-magnitude stars above the horizon — only six. And lonely Fomalhaut is now on the meridian — the only one of the six south of the celestial equator.

skylore

The constellation Piscis Austrinus (known as Piscis Australis until the 20th century) is far less famous than its finny relative Pisces, which lies in the zodiac. Yet Piscis Austrinus is an ancient constellation — one which Aratos strangely described as upside-down ("showing his belly's stars"). Author R.H. Allen states that early legend called it the parent of the two fish of Pisces. Whatever fame it has managed to win is surely due to its one star that easily outshines any in Pisces, or in all the other autumn constellations — Fomalhaut.

The name Fomalhaut is from the Arabic Fum al Hut, the Fish's Mouth, describing its location in the constellation (it is the recipient of Aquarius' streams of water). The early Arabs, presumably before Greek influence, called the star Al Difdi al Awwal, the First Frog. (The Second Frog was Beta [β] Ceti.) The name Fomalhaut is often mispronounced as if it were French — Fomalo — but should be sounded as "foam'l - hot." The name has been given an incredibly varied orthography: it has been spelled Fomahand, Fontabant, Fomauth, Phomault, and even Fomalcuti, among other odd forms.

The biggest mystery about the star's lore is that there is not more of it. Fomalhaut's unusual position of lone autumn splendor is responsible for its probably being one of the four Royal Stars of ancient Persia, one of the guardians of the heavens. Flammarion remarked that it was called Hastorang in Persia around 3000 B.C.; Allen mentions that it was worshipped in the temple of Demeter at Eleusis around 500 B.C. and was part of Dante's Tre Facelle — but perhaps all these claims should be looked at skeptically.

Author Robert Burnham, Jr. asserts that Fomalhaut was associated in Greek legend with perhaps the strongest monster of their mythology, Typhon. The Syrians may have believed that the star represented their rather unsavory Dagon — the god whose temple in Gaza was pulled down by Samson.

Burnham mentions that Fomalhaut appears to be traveling through space with the same proper motion as a sixth-magnitude star about 2° south of it — a star almost a light-year away from Fomalhaut. This might indicate that the two stars are the last members of an old cluster scattered by the Galaxy's rotation.

But to the naked eye, Fomalhaut certainly looks alone on an autumn night. Perhaps this solitude helped nominate Fomalhaut as one candidate for a "Central Sun of the Universe" in 19th century speculation.

Although Fomalhaut, unlike Canopus, is not too far from the ecliptic, it is the first-magnitude star farthest south of the *galactic equator* — just as Arcturus is the one farthest north. Rather surprisingly, Fomalhaut and Arcturus are not only at similar galactic latitudes for their respective hemispheres (Fomalhaut −65°, Arcturus +69°), but are also at similar galactic longitudes (20° and 14°, respectively). Although Fomalhaut and Arcturus are both rather close to us, Fomalhaut does not share the latter's distinctive motion, which plunges it rapidly through the galactic plane on a highly inclined orbit.

Aratos referred to Fomalhaut as "one large and bright by both the Pourer's feet." The great amateur astronomer Leslie Peltier simply called it the Autumn Star. But Fomalhaut has a special characteristic that we will come to appreciate fully only in a few decades, when we send human visitors and perhaps colonists to Mars. Viewed from the Red Planet, it should undergo nightly close conjunctions with the tiny moon Phobos and sometimes Deimos.

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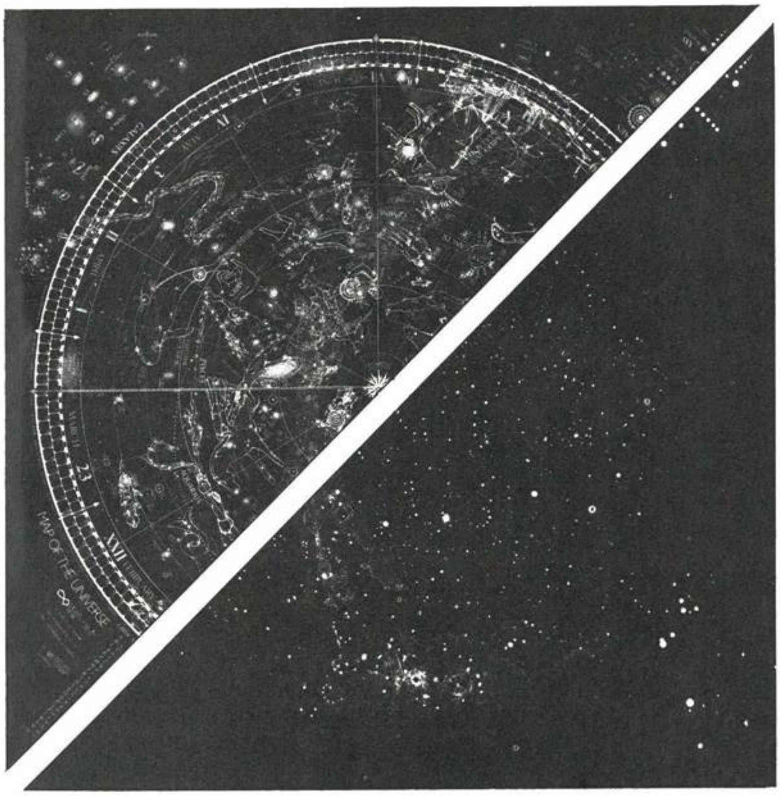

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VISA

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observing the autumn galaxies

by Alan Goldstein

Each season brings a different spectacle for deep-sky observers. Winter skies show bright Orion and the winter Milky Way. Spring skies remind observers of the realm of the galaxies. Summer skies? The Milky Way is at its grandest. The autumn skies? Well . . . er . . . hmmm! Let's face it, autumn isn't a season widely renowned for its deep-sky splendors. But there *are* exceptions — like M-31, the Andromeda Galaxy. And while M-31 is the brightest of the autumn galaxies, it is only one of many visible at this season in telescopes of moderate size.

Many observers tend to ignore the galaxies of autumn. Yet they are worth looking for, as they come in all shapes and sizes: spiral, elliptical, lenticular, irregular, peculiar, and interacting. Some of the most remarkable, heavily studied galaxies lie in the autumn "void," including virtually all of the Local Group members. So don't waste these cool steady nights — go galaxy hunting!

The Local Group

The Local Group is our local cluster of galaxies, which is in turn an outlying member of the Virgo supercluster of galaxies. We are closer to the "main body" of the supercluster than the largest Local Group member, M-31; thus, the Virgo cloud itself lies nearly opposite M-31 in our skies.

The first galaxy in our Local Group tour is NGC-6822, known as Barnard's Galaxy. (E.E. Barnard discovered it visually around the turn of the century.) Located in western Sagittarius, NGC-6822 must be observed early in the fall. It is a barred irregular galaxy of very low surface brightness, making it difficult to glimpse in progressively larger apertures (i.e., smaller fields of view). The best views come under dark skies with large-aperture binoculars, and then it appears as a hazy ellipse of light. It is visible in a 6-inch scope at low power under excellent conditions.

IC 10 is an obscure member lying near Beta (β) Cassiopeiae. It is visible through a "hole" in the Milky Way's dust clouds that generally absorb and block light from distant objects. This one is very difficult to observe visually: Its surface brightness is terribly low, but it just might be visible in a 6-incher under the darkest skies.

M-31, the Andromeda Galaxy, and its satellites, M-32 and NGC-205, compose the most observed system of galaxies in the heavens. This trio lies at the opposite end of the Local Group from us; M-31 itself is about one-third larger than the Milky Way. Under dark skies, binoculars and small scopes show several degrees' worth of spiral arms, and a 6-incher easily shows star cloud NGC-206 and the most prominent dark lane running alongside the galaxy. Telescopes 8 inches and larger show several globular clusters in the halo of M-31. They look like faint stars, however, and you'll need an accurate finder chart to differentiate them from Milky Way objects.

M-32 is bright and appears to lie beyond the main body of the Andromeda Galaxy. Actually, the dwarf elliptical is close enough to its master to be directly involved with M-31's gas and dust. NGC-205 lies on the other side of M-31 and is slightly larger and fainter than M-32. NGC-147 and NGC-185 are also dwarf elliptical satellites of M-31, but lie in southern Cassiopeia. Both are moderately large and have low surface brightnesses. To observe any of the small ellipticals, try using about 100x with at least a 4-inch scope. You'll be pleased at the subtlety of the misty light.

IC 1613 — called the Cetus System — is a dwarf irregular galaxy of extremely low surface brightness. It is a difficult object, requiring the clearest and darkest skies coupled with at least a 10-inch telescope.

M-33, the brightest galaxy in Triangulum, is often called the "Pinwheel Galaxy" (after its shape in photographs) and may just be visible to the unaided eye on dark nights. In binoculars it appears like a big ghostly patch lying between Alpha (α) Trianguli and Beta (β) Andromedae. M-33 is probably the best Northern Hemisphere galaxy in which to view detail — aided in large measure by its almost face-on aspect. The giant gas cloud NGC-604 is easy to spot in a 6-incher, and an 8-inch scope on a dark night reveals more of these HII regions: NGC-588, NGC-592, and NGC-595. Also visible in still larger scopes are the nebulae and star clouds IC 131/7, IC 142, and IC 143. The galaxy's spiral form is visible with an 8-inch scope and quite obvious in a 10-inch instrument.

The Fornax System is a strange, low-mass dwarf system that is virtually impossible to detect visually. Its integrated magnitude is a bright 9, but it is spread over four square degrees of sky, making it something like an expanded poor globular cluster. Whereas globulars have about 80 stars per square arc-minute, this galaxy has only 8. There is hope, however: If your telescope shows stars down to magnitude 12.5, you can observe one of the five globular clusters belonging to the Fornax System — NGC-1049.

The Large and Small Magellanic Clouds are also visible this time of year, but to obtain a good view of them you'll have to travel south to lands where it's spring.

The Sculptor Group

The Sculptor group is one of the two closest systems of galaxies beyond the Local Group. (The other is the M-81 group, visible in spring.) Although six southern spiral galaxies compose the Sculptor group, only two are easy to observe. NGC-7793 is a pale ghostly object, not unlike a distant version of M-33. It is visible in small scopes but requires a clear southern horizon because of its near −33° declination.

At magnitude 7.8, NGC-55 is the second brightest member of the Sculptor Group. It is a large edge-on barred spiral and makes a spectacular sight in large telescopes. Although it has a fairly low surface brightness, the galaxy shows some detail; under favorable skies you might be able to detect the star cloud in the closer arm, distinctly separated from the galaxy's central hub.

In southern Cetus is NGC-247, the northernmost member of the group. It is a 10th magnitude object and has a peculiar shape, appearing as a fan-like oval. This fairly large spiral has a rather low surface brightness and thus demands a wide field for good viewing.

NGC-253 is the brightest galaxy in the Sculptor Group and one of the finest galaxies in the sky. Shining at magnitude 9, this beautiful spiral is inclined only 12° from edge-on, which gives it a high surface brightness. A fine sight even in binoculars, NGC-253 lies only 2½° north of the south galactic pole. Wide-field telescopes show the silvery mottled galaxy in the same low-power field with NGC-288, an old, loose globular cluster.

Perhaps the most difficult to observe of any Sculptor galaxies is NGC-300, a large 11th magnitude Sc-type spiral with a low surface brightness. The galaxy's southerly declination of −38° makes it a tough target for North Americans, but binoculars or an RFT on a good dark night may show the system.

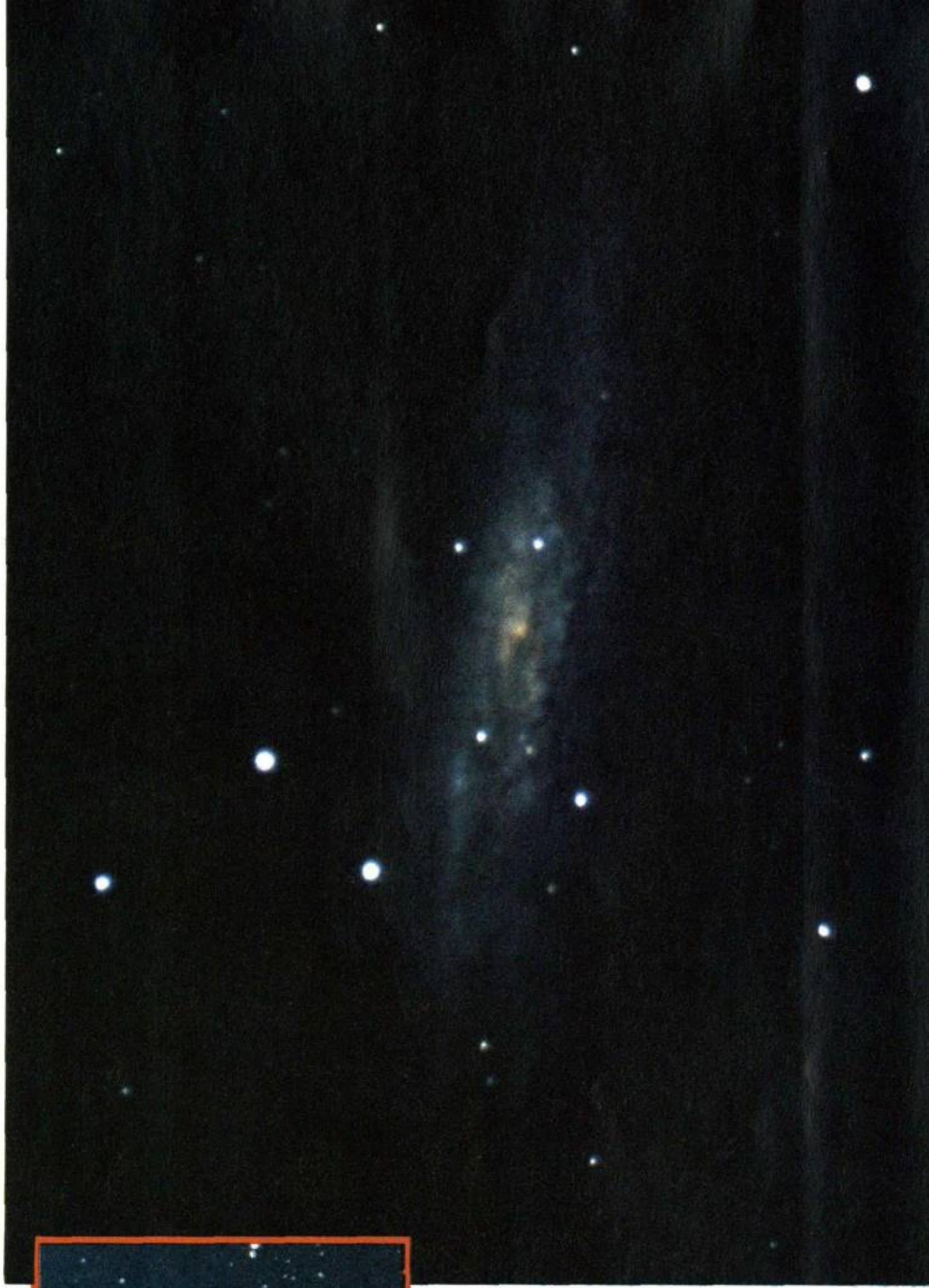
The Fornax Cluster

Autumn's equivalent of the Virgo Cluster is the Fornax Cluster. The brightest galaxy in this grouping is the peculiar NGC-1316, also called Fornax A because it was the first radio source discovered in the constellation. This 10th magnitude object and NGC-1317 just to the north make a pretty pair. The best view of this cluster comes by centering on NGC-1387, a 12th magnitude barred spiral. If you have a 1° field of view and a scope of moderate size, you'll see *nine* galaxies in one field: NGC-1374, NGC-1379, NGC-1380, NGC-1381, NGC-1386, NGC-1387, NGC-1389, NGC-1399, and NGC-1404. This compares favorably with the heart of the Virgo Cluster, where an average telescope reveals eight galaxies. If you use the *Sky Atlas 2000.0,* note that NGC-1365 is incorrectly marked on charts 18 and 19 as NGC-1305.

Other Galaxies

The autumn skies hold many other bright galaxies. M-31 is a jump-off point for several located west of the great spiral. The first is NGC-7640, an edge-on barred spiral in Andromeda near the planetary nebula NGC-7662. This galaxy is inclined only 11° to our line of sight, causing it to appear as a very thin ray of light. It is visible in small scopes.

Southwest of NGC-7640 is NGC-7331, the brightest galaxy in Pegasus. This fine galaxy lies just east of a point midway between a line drawn from Eta (η) Pegasi to 1 Lacertae. NGC-7331 is a bright, nearly edge-on Sb galaxy, and a large telescope shows several fainter galaxies in the same field of view. A mere 40′ south of 7331 is one of the most curious sky objects, Stephan's Quintet (NGC-7317, NGC-7318A, NGC-7318B, NGC-7319, and NGC-7320). Composed of five faint galaxies (four of which are physically connected), the group is visible in



Above: NGC-253, a large, nearly edge-on galaxy in Sculptor, displays a bright yellowish starlike nucleus embedded in its greenish mottled arms. Photo by Bill Iburg, using a 14-inch SCT at f/5.5, 200 ASA emulsion pushed to 400 ASA, and a 35-minute cold camera exposure.
Left: Martin C. Germano photographed NGC-205 — one of M-31's companions — by loading his camera with 103a-F film and guiding his 8-inch f/10 telescope during a 60-minute exposure.

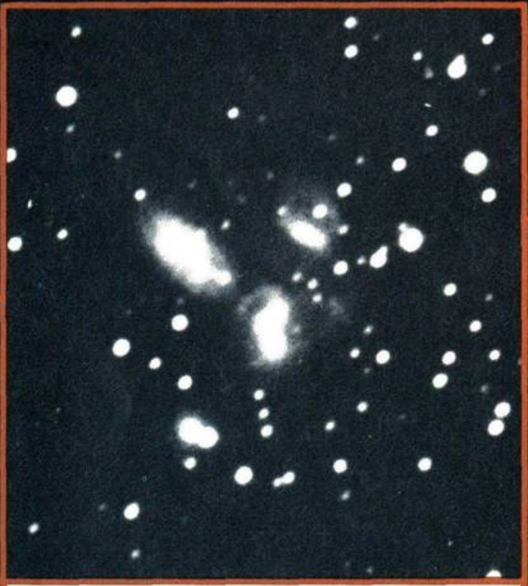
moderate sized telescopes: I found it difficult in an 11-inch and easy in a 20-inch. Under dark skies a 6-inch shows the brightest galaxy, NGC-7320.

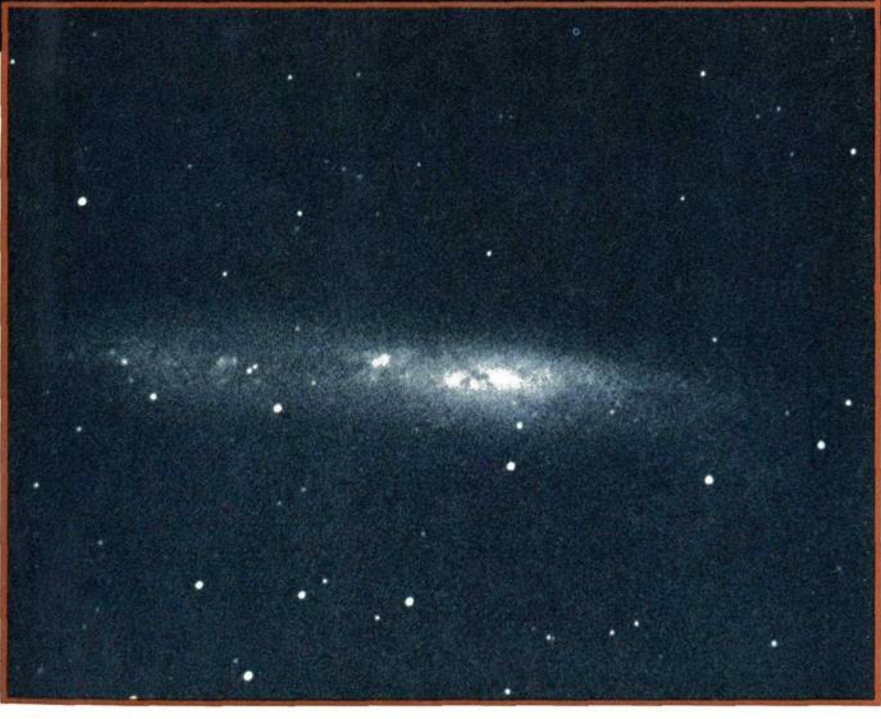
NGC-6946 is a Sc galaxy that lies on the Cepheus-Cygnus border. Five supernovae have appeared in this galaxy since 1900, most recently in 1980. NGC-6946 is nearly face-on, and like other face-on systems it is a difficult object because of low surface brightness. The galaxy suffers slightly from Galactic obscuration — it's about 12° off the plane of the Milky Way — but a 6-inch scope shows it under good skies, and large amateur scopes begin to resolve the spiral arms.

M-33 is the jump-off point for several interesting galaxies. NGC-404 is one of the easiest galaxies to locate, but a difficult one to see. The problem is that it lies in the same field as second-magnitude Beta (β) Andromedae — the galaxy is bright, but glare from the star obliterates it in anything smaller than 6 inches in aperture. NGC-404 is a lenticular galaxy and probably belongs to our Local Group. About 4° southeast of M-33 is a faint trio of galaxies: NGC-670, NGC-672, and IC 1727. NGC-670 and NGC-672 are fairly bright and are visible in an 8-incher, but IC 1727 — a very loose spiral with a low surface brightness — is satisfyingly difficult.

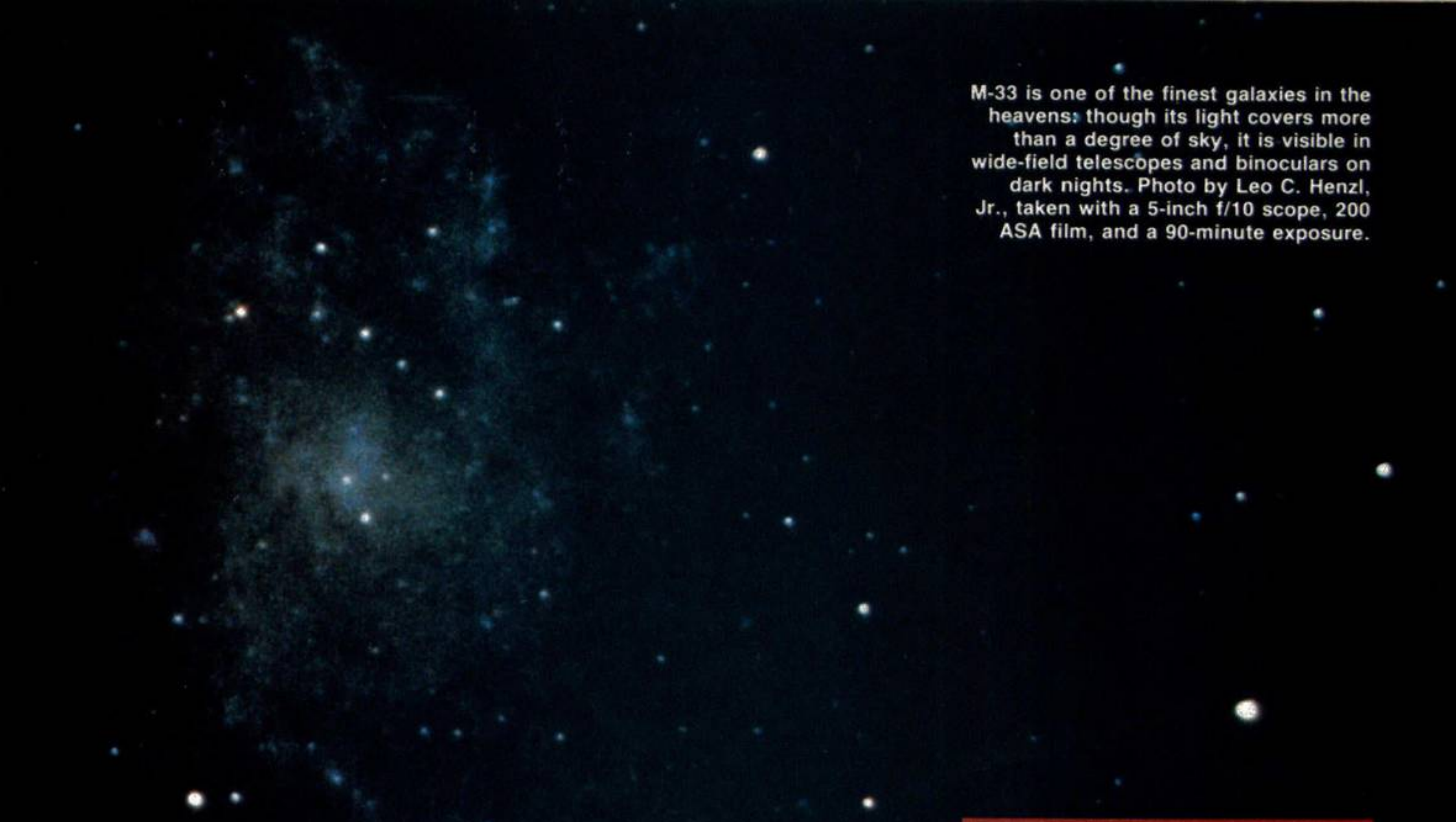
One of the best edge-on galaxies in the sky is the low surface brightness object NGC-891. This galaxy is a slightly fainter, smaller version of NGC-4565 in Coma Berenices; they both show a prominent dark lane. A 6-inch scope reveals a thin silvery spike and the relatively thick bisecting dust lane — successively larger telescopes don't reveal too much more about this galaxy.

Two degrees east-northeast of Algol

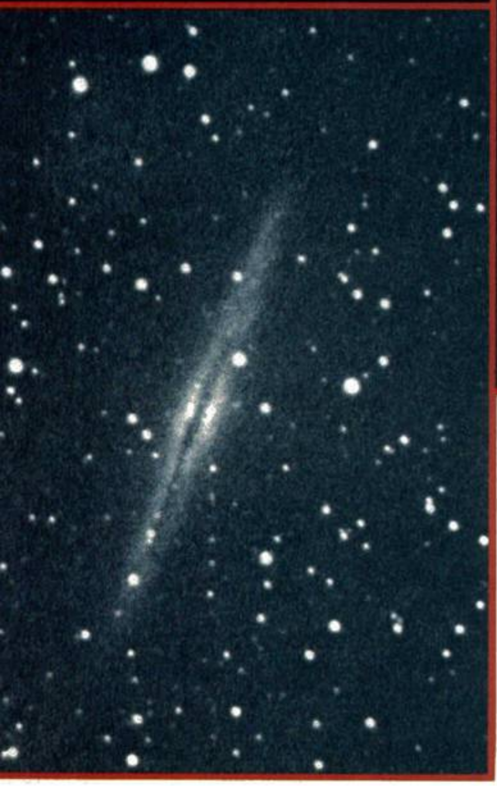


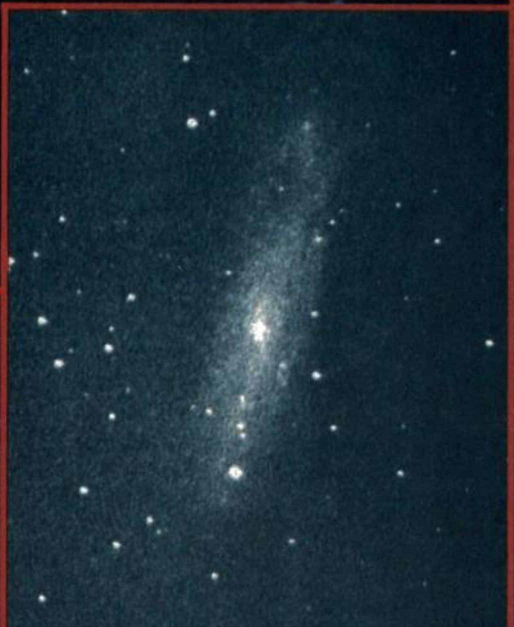


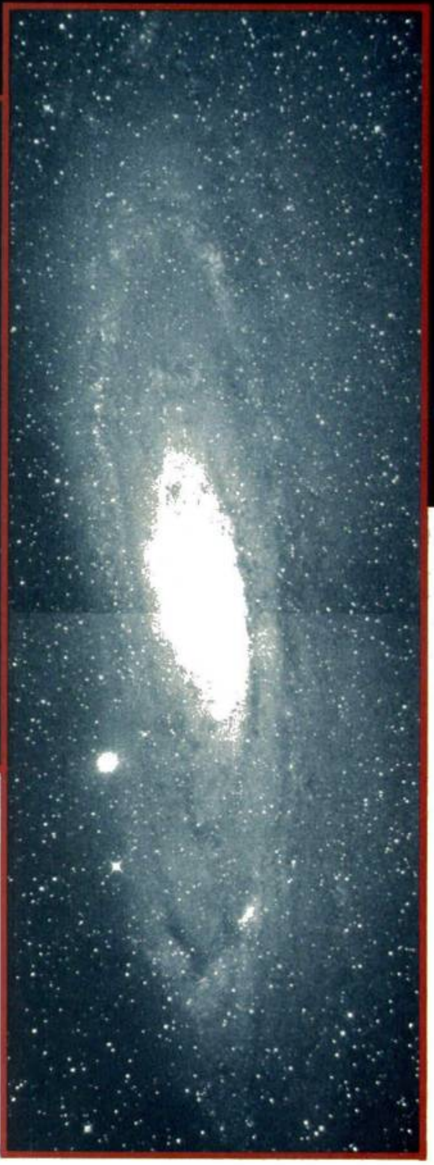
Left: NGC-55 is a tough target for amateur galaxy hunters — its spindle shape and low surface brightness require a low-power large scope view. Photo by Martin C. Germano, taken with an 8-inch f/10 SCT, 103a-F film, and a 55-minute exposure. Above: A difficult object to see, Stephan's Quintet is composed of four associated galaxies — and a fifth, much closer to us than the rest. K.A. Brownlee took this photo in a 20 minute exposure with his 16-inch f/5 Newtonian.



M-33 is one of the finest galaxies in the heavens: though its light covers more than a degree of sky, it is visible in wide-field telescopes and binoculars on dark nights. Photo by Leo C. Henzl, Jr., taken with a 5-inch f/10 scope, 200 ASA film, and a 90-minute exposure.







Left: NGC-891, photographed by Martin C. Germano. The 8-inch f/10 exposure on 103a-F lasted 80 minutes. Above: In an 8-inch f/5, 40-minute shot by Martin C. Germano, NGC-247 — a galaxy with low surface brightness — barely reveals its tenuous spiral arms. Visually, they are difficult at best to detect. Right: Lee C. Coombs used his 10-inch f/5 Newtonian to make two off-centered 15-minute exposures of M-31. Combining them, he created this full-length 103a-O montage of the Andromeda Galaxy.

autumn galaxies

NGC	R.A.(1950)Dec.		Mag.	Type
6822	19h 42.1m	−14° 53′	9.2	IB
6946	20h 33.9m	+59° 58′	9.7	Sc
7184	21h 59.9m	−21° 04′	12.0	Sb
7217	22h 05.6m	−31° 07′	11.0	Sb
7314	22h 33.0m	−26° 18′	11.6	Scp
7317-20	22h 34.8m	+33° 40′	14.0	Group
7331	22h 34.8m	+34° 10′	9.7	Sb
7332	22h 35.0m	+23° 32′	11.8	SO
7448	22h 57.6m	+15° 43′	11.2	Scp
7479	23h 02.4m	+12° 03′	11.6	SBb
7606	23h 16.5m	−08° 46′	11.5	Sb
7640	23h 19.7m	+40° 35′	11.3	SBb
7723	23h 36.4m	−13° 14′	11.1	Sb
7727	23h 37.3m	−12° 34′	10.7	SOp
7793	23h 55.3m	−32° 51′	9.7	Sd
7814	00h 00.7m	+15° 51′	12.4	Sa
55	00h 12.5m	−39° 30′	7.8	SBm
IC 10	00h 17.6m	+59° 02′	12.4	SBm or I
147	00h 30.4m	+48° 14′	12.1	E5p
157	00h 32.3m	−08° 40′	11.2	Sc
185	00h 36.1m	+48° 04′	11.7	E3
205	00h 37.6m	+41° 25′	9.4	E5
224 M-31	00h 40.0m	+41° 00′	4.8	Sb
221 M-32	00h 40.0m	+40° 36′	8.7	E2
247	00h 44.6m	−21° 01′	9.5	Sd
253	00h 45.1m	−25° 34′	8.9	S(B)c
278	00h 49.2m	+47° 18′	11.3	Sb
SMC	00h 50.0m	−73° 00′	1.5	I
300	00h 52.6m	−37° 58′	11.3	Scd
IC 1613	01h 02.5m	+01° 52′	10.4	I
404	01h 06.6m	+35° 27′	10.7	SO
470	01h 17.1m	+03° 09′	12.5	Sb
474	01h 17.5m	+03° 10′	11.9	SO
488	01h 19.1m	+05° 00′	11.1	Sb
520	01h 22.0m	+03° 32′	12.4	Pec
521	01h 22.0m	+01° 28′	13.0	SBb
598 M-33	01h 31.1m	+30° 24′	6.7	Sc
613	01h 32.0m	−29° 40′	10.2	SBc
628 M-74	01h 34.0m	+15° 32′	10.2	Sc
670	01h 44.5m	+27° 38′	13.0	SO?
IC 1727	01h 44.6m	+27° 05′	13.5	SBm
672	01h 45.0m	+27° 11′	12.2	SBc
681	01h 46.7m	−10° 40′	12.8	Sa
720	01h 50.6m	−13° 59′	10.5	E5
750/1	01h 54.6m	+32° 58′	13.7	EO/EO
772	01h 56.6m	+18° 46′	10.9	Sbp
821	02h 05.6m	+10° 46′	11.2	E6
891	02h 19.3m	+42° 07′	10.9	Sb
925	02h 24.3m	+33° 22′	10.5	SBc
936	02h 25.1m	−01° 22′	10.7	SBa/SBO
972	02h 31.3m	+29° 06′	12.7	Sc
985	02h 32.6m	−08° 57′	14.0	Pec
Fornax	02h 37.0m	−34° 40′	9.0	Dwarf
1023	02h 37.2m	+38° 52′	10.5	SOp
1068 M-77	02h 40.1m	−00° 14′	8.9	Sbp
1073	02h 41.2m	+01° 10′	11.4	SBc
1084	02h 43.5m	−07° 47′	11.0	Sc
1097	02h 44.3m	−30° 29′	10.6	SBbp
1140	02h 52.2m	−10° 24′	12.8	Pec
1156	02h 56.7m	−25° 03′	11.8	I
1199	03h 01.3m	−15° 48′	12.7	E2
1232	03h 07.5m	−20° 46′	10.5	Sc
1291	03h 15.5m	−41° 17′	10.2	SBO
1275	03h 18.5m	+41° 20′	12.5	Pec
1300	03h 17.5m	−19° 35′	11.1	SBb
1313	03h 17.6m	−66° 40′	10.8	SBc
1316	03h 20.7m	−37° 25′	10.1	Pec
1332	03h 24.1m	−21° 31′	10.4	SO
1337	03h 25.6m	−08° 34′	12.3	Sc
1365	03h 31.8m	−36° 18′	11.2	SBb
1387	03h 35.1m	−35° 41′	12.1	SBO
1398	03h 36.8m	−26° 30′	10.4	SBb
1400	03h 37.2m	−18° 51′	10.7	E1/SO
1406	03h 37.5m	−31° 28′	12.7	Ab?
1407	03h 37.9m	−18° 44′	10.6	EO
1421	03h 40.2m	−13° 40′	12.0	Sb
IC 342	03h 41.9m	+67° 57′	12.0	Sc
1512	04h 02.3m	−43° 29′	11.8	SBap
1553	04h 15.2m	−55° 54′	10.2	SOp
1566	04h 18.9m	−55° 04′	10.5	Sc
1569	04h 26.0m	+64° 45′	11.8	Ip
1792	05h 03.5m	−38° 04′	10.7	Scp
LMC	05h 26.0m	−69° 00′	0.5	SBm
1964	05h 31.2m	−21° 59′	11.6	Sc
1961	05h 36.8m	+69° 24′	11.7	Sbp

(Beta [β] Persei) lies the famous Perseus galaxy cluster. Most of the galaxies in this group are 14th to 16th magnitude, so you'll need at least a 16-incher to see much. NGC-1275 is the brightest member of this cluster and one of the strangest galaxies known. Also called Perseus A, it is a Seyfert galaxy, but one that doesn't quite fit into either of the two subclasses. Although practically all Seyferts are spirals, NGC-1275 is an elliptical. NGC-1275 may be representative of a group of objects known as N-Galaxies — slightly higher-energy critters than Seyferts, but more mild-mannered than BL Lacertae objects and quasars. This mysterious galaxy should be visible in a 6-inch scope under very dark skies.

M-74 is a face-on spiral in Pisces. Observationally it is one of the most difficult Messier objects, but it is nevertheless visible in a 6-incher under good conditions. Under ideal skies, even scopes of modest aperture begin to show spiral structure in this galaxy. M-77 is a rather isolated Messier object found near the star Delta (δ) in the galaxy-rich constellation Cetus. The closest example of a Seyfert galaxy to us, it shows a stellar nucleus and tightly wound inner and outer spiral arms. Five fairly bright galaxies lie near M-77: NGC-1055 and NGC-1073 to the north, NGC-1087 and NGC-1090 to the east, and NGC-1032 to the northwest. Nearly 9° south-southwest of M-77 is NGC-985, an intrinsically faint Seyfert ring galaxy — the only such object known. It shines at 14th magnitude and is a challenge for 10-inch telescopes. If you have a large scope, see what this oddity looks like.

Lying north of the Fornax System is NGC 1097, an unusual barred spiral that seems to be undergoing violent dynamical activity. Like NGC-770, the object has a small elliptical companion and displays symmetrical "jets" of highly ionized material emanating from the nucleus, possibly shot out by a black hole in the galaxy's core. The jets are, however, much too faint to observe visually.

There are many galaxies worth observing in the autumn skies; the table above lists most of the bright ones. Many of these objects, such as M-31, NGC-253, M-33, etc., are easily observed with small telescopes under average skies. But the great bulk of these vast stellar systems demands dark skies, fine equipment, and careful, patient gazing. If you are willing to stalk these autumn galaxies, you'll be rewarded with the bounty of seeing a hundred trillion suns and contemplating a billion unseen worlds. The autumn galaxies await you!

Alan Goldstein is director of the National Deep-Sky Observers Society, a group of dedicated galaxy, nebulae, and cluster hunters, and a frequent contributor to Deep Sky *magazine. He is a graduate student in terrestrial geology.*

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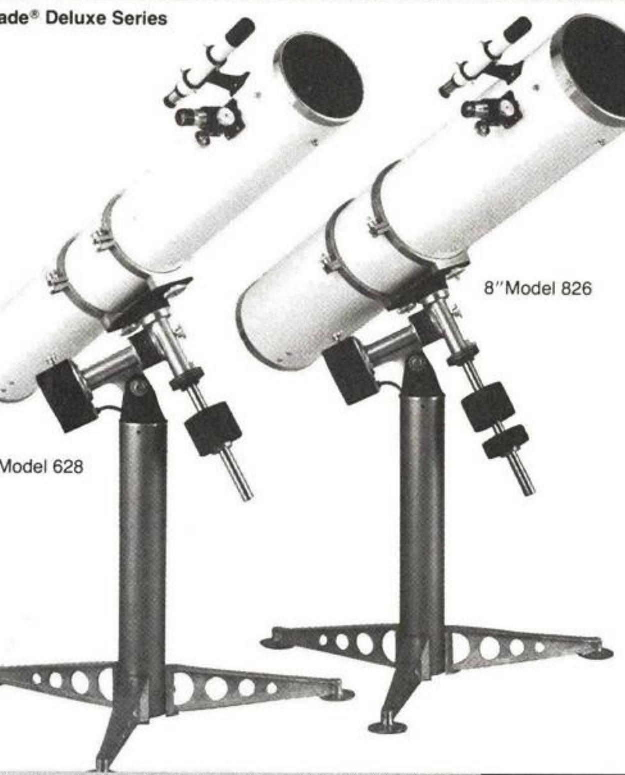

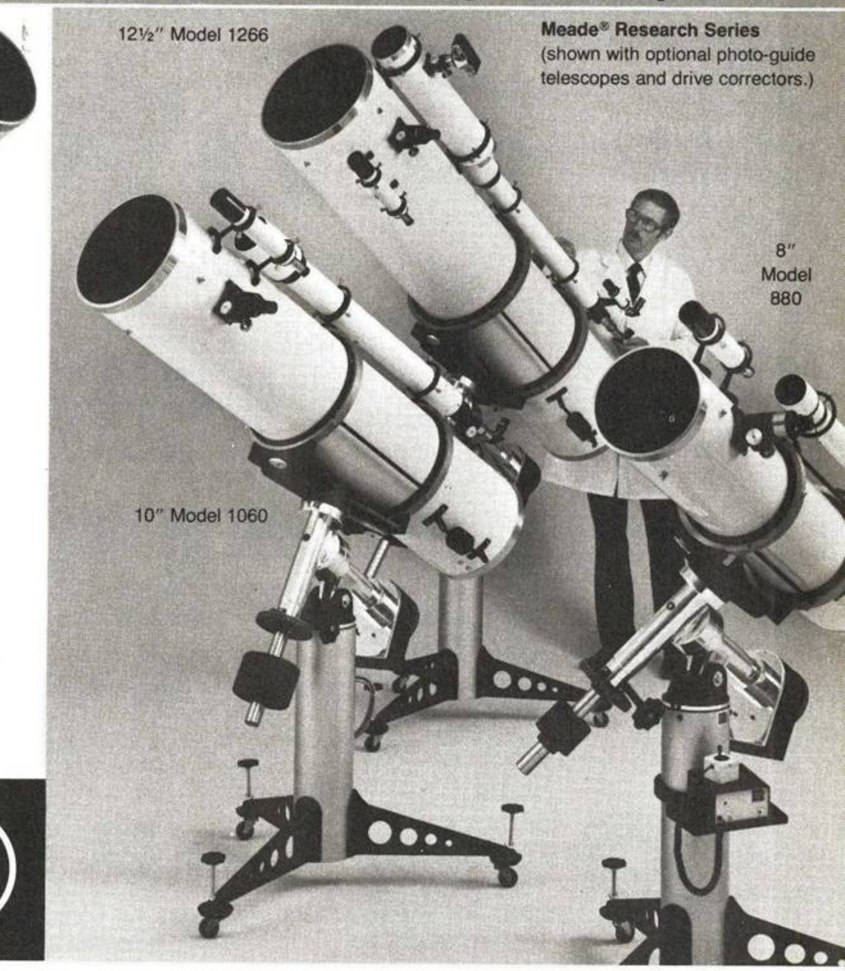
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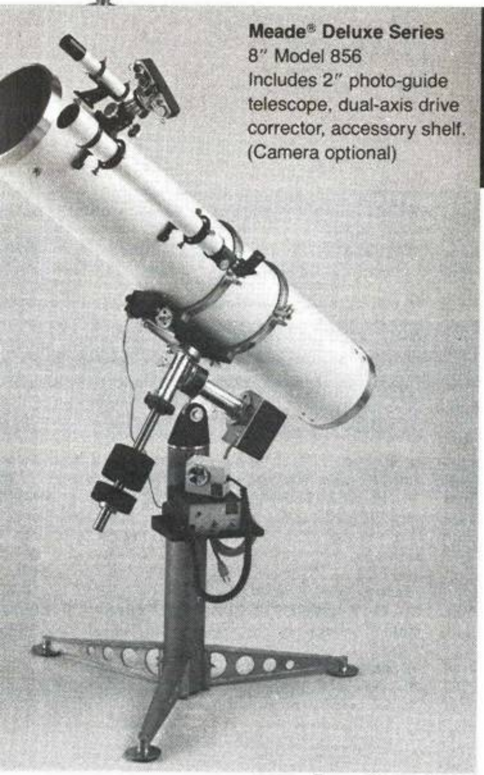
(shown with optional photo-guide
telescopes and drive correctors.)
8″
Model
880
10″ Model 1060



Meade® Deluxe Series
8″ Model 856
Includes 2″ photo-guide telescope, dual-axis drive corrector, accessory shelf. (Camera optional)

Meade Deluxe Series 6″ and 8″ Reflecting Telescopes

The most popular reflecting telescopes in the World for the serious amateur. Diffraction-limited 1/10-wave parabolic primary mirrors with matching elliptical flat secondaries. Mounts machined to .001″ tolerances for a lifetime of precision tracking, visually and photographically. Polar and Dec. shafts 1″ dia. solid steel. Complete with Motor Drive (115V./60Hz) and automatic clutch; setting circles; 2 Modified Achromatic eyepieces threaded for filters; 6 x 30 achromatic viewfinder; rack and pinion focuser; rotating ring system. Fiberlite tube with ultrahard white epoxy coating and metal trim rings. Excellent astrophotographic capabilities with your 35mm camera.

Meade Research Series 8″, 10″, 12½″ Reflecting Telescopes

For the advanced observer/astrophotographer, the largest-selling instruments of their kind, by far. Oversize equatorial mounts with double Sealmaster ball-bearings, 1½″ solid steel shafts, 6″ engraved setting circles, and machined Nylon-bearing tube rotation system. Diffraction-limited 1/10-wave optics. Standard accessories: giant #680 focuser for 1¼″ and 2″ O.D.; 8 x 50 viewfinder; 2 multi-coated Orthoscopic eyepieces.

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exact same Equatorial
nts used on Meade De-
and Research Series
copes are available for
rate purchase. Each
nt includes equatorial
with motor drive, set-
circles, and saddle
; pier; tripod legs.
cradle rings available
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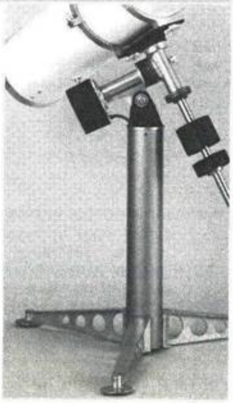

PRICE LIST

COMPLETE DELUXE SERIES TELESCOPES	
Model 628: 6″ f/8 with Motor Drive	$ 519.50
Model 645: 6″ f/5 with Motor Drive	529.50
Model 826: 8″ f/6 with Motor Drive	649.50
Model 856: 8″ f/6 with Motor Drive, 2″ Guide Telescope, Dual-Axis Drive Corrector, Accessory Shelf	979.50
COMPLETE RESEARCH SERIES TELESCOPES	
Model 880: 8″ f/6 with Motor Drive	$1575.00
Model 1060: 10″ f/6 with Motor Drive	1985.00
Model 1266: 12½″ f/6 with Motor Drive	2495.00

COMPLETE EQUATORIAL MOUNTS	
Model 652: 6″ with Motor Drive	$ 225.00
Model 852: 8″ with Motor Drive	260.00
Model 1071: 10″ with Motor Drive	1025.00
Model 1277: 12½″ with Motor Drive	1075.00

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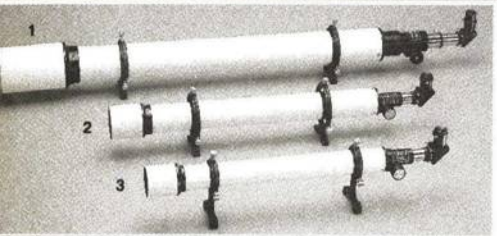
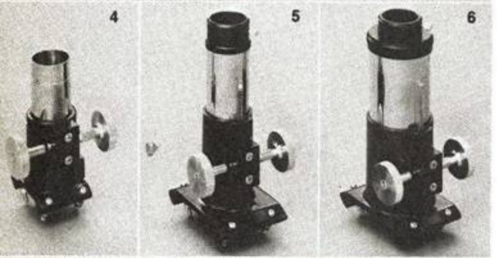
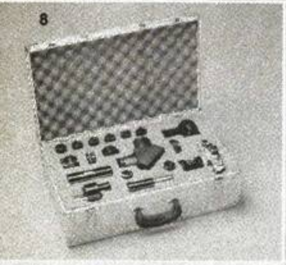
For toll-free dealer locations or factory-direct ordering assistance please turn the page.

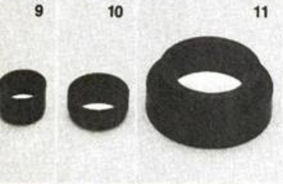
⇨

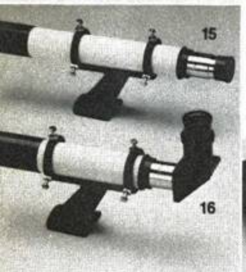
Meade® Research Quality Accessories & Parts

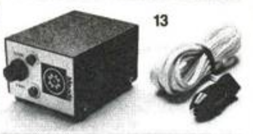


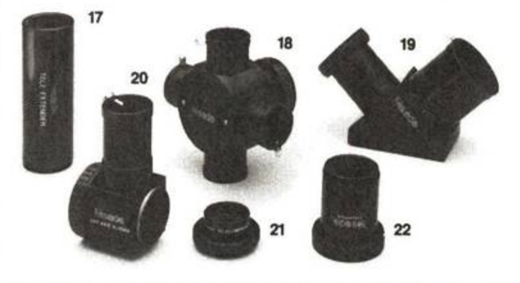


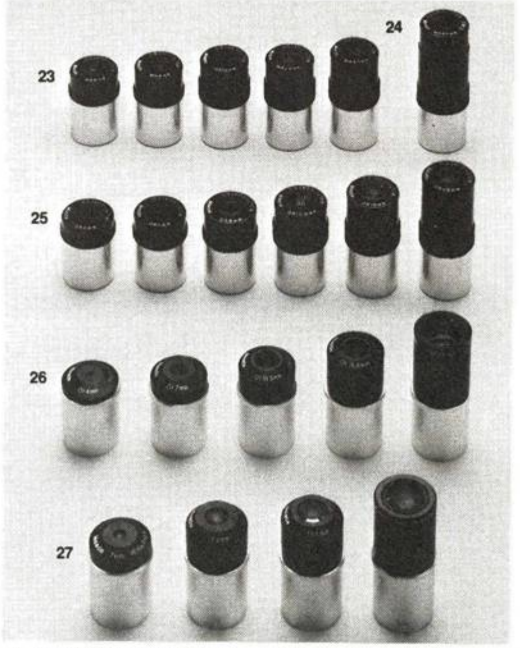


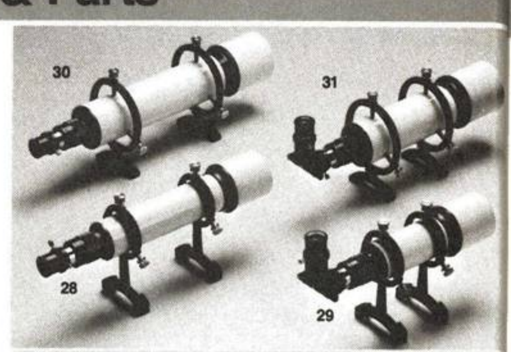


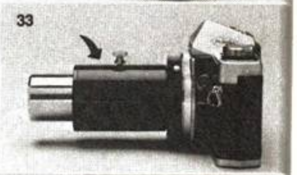


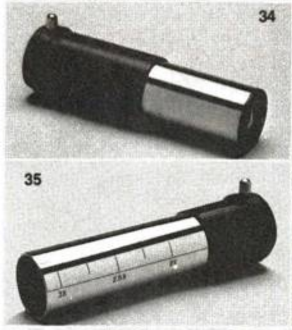


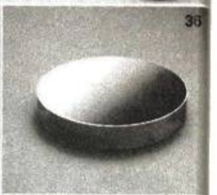


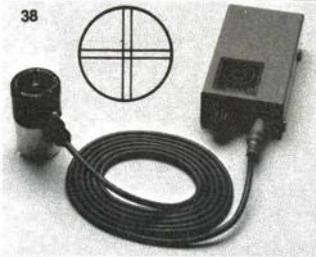












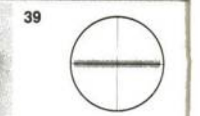


PHOTO-GUIDE TELESCOPES—Each with coated, air-spaced objective, rack-and-pinion focuser, diagonal prism, 9mm crosshair eyepiece.

1—**Model 300PG:** D=80mm (3.1"); F=1200mm (f/15) . . . **$215.00 ppd.**
2—**Model 280PG:** D=60mm (2.4"); F=700mm (f/11.7) . . . **$89.50 ppd.**
3—**Model 210PG:** D=50mm (2.0"); F=600mm (f/12) . . . . . **$69.50 ppd.**
Mounting Rings: for #210PG . . . . per pr. **$12.50 ppd.**
for #280PG, #300PG . . . . per pr. **$14.50 ppd.**

RACK-AND-PINION FOCUSERS—All 3 models include helical-cut rack and variable-tension adjustment for ultra-smooth focusing without backlash. Universal bases fit all tube sizes. Standard 1¼" eyepiece holders.

4—**Model 67**—Strong, lightweight design for 4" to 10" telescopes. 2-3/16" travel. An excellent value. . . . . **$24.95 ppd.**
5—**Model 640** — A heavy-duty deluxe focuser for 6" to 16" telescopes. Full 3" travel for both visual and photographic applications. . . . . **$39.95 ppd.**
6—**Model 680**—Accepts both 1¼" and 2" eyepieces. Full 3" travel for photo or visual observing with 6" to 18" telescopes. . . . . **$49.95 ppd.**

ACCESSORY CASES—For secure storage of eyepieces, Barlows, filters.

7—**Model 54:** Thick-wall polyethylene with latch and handle. Holds 7 eyepieces & Barlow, filters. Dims. 12" x 8" x 3¾" . . . . . **$14.50 ppd.**
8—**Model 50:** Luggage-quality metal case with 2 latches, handle; foam custom fits to your accessories. Dims. 20" x 12" x 6½" **$49.50 ppd.**

NEBULAR FILTERS—Revolutionary 3-channel filters block natural airglow & sodium and mercury emissions from city lights. Dramatically improve telescope performance visually and photographically.

9— **Model 907:** 18mm aperture, for .965" O.D. eyepieces . . **$49.95 ppd.**
10—**Model 908:** 23mm aperture, for 1¼" O.D. eyepieces . . **$55.00 ppd.**
11—**Model 911:** 36mm aperture, threads directly onto rear-cell of Meade and other brands of Schmidt-Cassegrains. . . . . **$79.50 ppd.**

12—**PHOTO-VISUAL COLOR FILTERS**—Top quality optical glass, dyed-in-the-mass, with excellent spectral homogeneity. Thread directly into 1¼" O.D. barrels. Filters may be piggybacked. **#8 Light Yellow—#11 Yellow-Green—#12 Yellow—#21 Orange—#23A Light Red—#25A Red—#47 Violet—#58 Green—#80A Blue—Polarizer (30% transmission).** Each **$8.95 ppd.**

13—**VARIPAK DRIVE CORRECTOR—Model 43:** Supercompact 2" x 3" x 4" design. Fast-slow pushbuttons. Variable speed control. Operates from 12 volts D.C., plugs into standard auto cigarette lighter The 12-watt output is sufficient for most telescopes to 14" aperture . . . . **$69.50 ppd.**

14—**VARIGUIDE DRIVE CORRECTOR — Model 41:** The finest R.A. drive corrector available. Includes aircraft-type joystick controller for continuously variable correction rates. Variable speed control. Use with any telescope drive rated up to 12 watts. Operates from 12 v. D.C. or 115 v. A.C. . . . . **$135.00 ppd.**

15—**6 x 30mm VIEWFINDER—Model 631:** Actual field: 4°. Includes coated, achromatic objective lens and crosshair eyepiece. Precise push-pull focusing. Thousands now in use. Bracket with collimation screws and lock-nuts, included. Bracket fits all tubes 6" to 12½". . . . . **$29.50 ppd.**

16—**6 x 30mm RIGHT-ANGLE VIEWFINDER—Model 633:** As in (15), but with prism for convenient right-angle observations. Prism may be rotated 360° for maximum viewing comfort. 2-ring bracket included. . . . . **$36.50 ppd.**

SCHMIDT-CASSEGRAIN ACCESSORIES—The finest obtainable. For Meade and other brands.

17—Tele-Extender . . . . **$22.50 ppd.**
18—Rotary Eyepiece Holder (holds 4 eyepieces) . . . . **$75.00 ppd.**
19—2" Diagonal Mirror (1/10-wave) . . . . **$160.00 ppd.**
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21—Telecompressor (multi-coated) . . . . **$36.00 ppd.**
22—T-Adapter . . . . **$22.50 ppd.**

23—**SERIES 2 MODIFIED ACHROMATIC EYEPIECES (1¼" O.D.; MULTI-COATED)**—Custom 3-element designs, precisely corrected for chromatic and spherical aberrations. Finest obtainable under $25.
FOCAL LENGTHS: MA 6, 9, 12, 25mm, 40mm Wide-Field, ea. . . . . **$23.50 ppd.**

24—**MODIFIED ACHROMATIC 40mm EXTRA-WIDE-FIELD EYEPIECE (1¼"O.D.; MULTI-COATED)**—Yields widest field obtainable in 1¼" O.D. Enlarged field lens and special field-flattening optics with long eye relief . . . . **$32.50 ppd.**

25—**SERIES 2 ORTHOSCOPIC EYEPIECES (1¼" or .965" O.D.; MULTI-COATED, PARFOCAL)**—The excellent 4-element high resolution optics of these oculars are all the majority of serious amateurs ever require. Razor sharp 45° fields. Both 1¼" and .965" O.D. sets parfocalized.
FOCAL LENGTHS: OR 4, 6, 9, 12.5, 18, and 25mm . . . . **each $32.50 ppd.**

26—**RESEARCH-GRADE ORTHOSCOPIC EYEPIECES (1¼" O.D.; MULTI-COATED; PARFOCAL)**—The largest selling premium-quality eyepieces in the world, universally acclaimed to be the finest eyepieces obtainable. 4-element systems, unsurpassed in color correction, resolution, and flatness of field. 45° field. **OR 4, 7, 10.5 16.8, 28mm** . . . . **each $46.50 ppd.**

27—**RESEARCH-GRADE ERFLE EYEPIECES (1¼" O.D.; MULTI-COATED; PARFOCAL)**—For breathtaking wide-angle observations. 65° fields, parfocalized with our Research-Grade Orthoscopics. **FOCAL LENGTHS: ER 7, 12.4, 15.5, 20mm . . each $54.50 ppd.**

VIEWFINDERS — With helical focusers for ultraprecise control of image sharpness. Coated, achromatic objectives of new Meade design yield fully corrected images throughout the field. Actual field on 50mm models: 4¼°, on 60mm models: 3½°. Crosshair eyepiece, dewcap, dustcap included.

28—**8 x 50mm—$52.50 ppd.** Brackets: **$12.50/pr. ppd.**
29—**8 x 50mm RIGHT-ANGLE—$59.50 ppd.** Brackets: **$12.50/pr. ppd.**
30—**GIANT 9 x 60mm—$77.50 ppd.** Brackets: **$12.50/pr. ppd.**
31—**GIANT 9 x 60mm RIGHT ANGLE—$84.50 ppd.** Brackets: **$14.50/pr.**

32—**RESEARCH-GRADE ERFLE 32mm EYEPIECE (2" O.D.; MULTI-COATED)**—Wide-angle, fully-corrected 65° field. The finest eyepiece obtainable in 2" barrel. **$110.00 ppd.** Adapter Barrel for 1¼" O.D. **$12.00 ppd.**

33—**DELUXE CAMERA ADAPTERS**—Adapt your camera to telescope focuser instantly. Individually machined from solid bar aluminum and brass. All units permit both eyepiece-projection and first (prime) focus photography. Specify your camera brand and either 1¼" or .965" focuser. All 1¼" units are threaded for filters. **Nikon, Canon, Minolta, Pentax K, Konica, Olympus OM, or Universal Thread-Mount** . . . . . **$29.50 ppd.**

34—**2X and 3X TELENEGATIVE AMPLIFIERS (1¼" O.D.; MULTI-COATED)**—Warranted without qualification to be the world's finest Barlow lenses. Full 26mm clear apertures. Multi-Coated, with virtually flawless optical corrections at all photo-visual wavelengths on any telescope. **2X Model 122:** . . . **$32.50 ppd; 3X Model 123:** . . . **$35.00 ppd; 2X Model 131:** Per Model 122, but for 965" focusers, 18mm clear aperture, Multi-Coated . . . . **$27.50 ppd.**

35—**2X-3X VARIABLE TELENEGATIVE AMPLIFIER (1¼" O.D.; MULTI-COATED)—Model 127:** Made to same research standards as Model 122 above, but mounted in a machined sliding cell, for variable power settings between 2X and 3X. Engraved scale indicates power. Multi-Coated . . . . **$39.95 ppd.**

36—**PARABOLIC MIRRORS** — The very finest. 1/10-wave, diffraction-limited primary mirrors. Aluminized and quartz overcoated. Immediate shipment. **6" f/8 . . . $69.50 ppd.; 6" f/5 . . . $80.00 ppd.; 8" f/6 . . . $110.00 ppd.; 10" f/6 . . . $250.00 ppd.; 12½" f/6 . . . $425.00 ppd.**

37—**SECONDARY MIRRORS** — Elliptical 1/10-wave flats. Aluminized and overcoated. Immediate shipment. **1.30" M.A. . . . $13.00 ppd.; 1.52" M.A. . . . $17.50 ppd.; 1.83" M.A. . . . $21.00 ppd.; 2.14" M.A. . . . $24.75 ppd.; 2.60" M.A. . . . $29.50 ppd.; 3.10" M.A. . . . $52.50 ppd.**

38—**ILLUMINATED RETICLE GUIDING EYEPIECE (1¼" O.D.)**—New phosphorescent etched double-line reticle permits line illumination from dim to extremely bright. Remote brightness control and 6 ft. cable. Modified Achromatic 12mm optical system. Precisely focusable reticle. Complete . . . **$59.50 ppd.** Interchangeable barrel for .965" O.D. . . . **$7.50 ppd.**

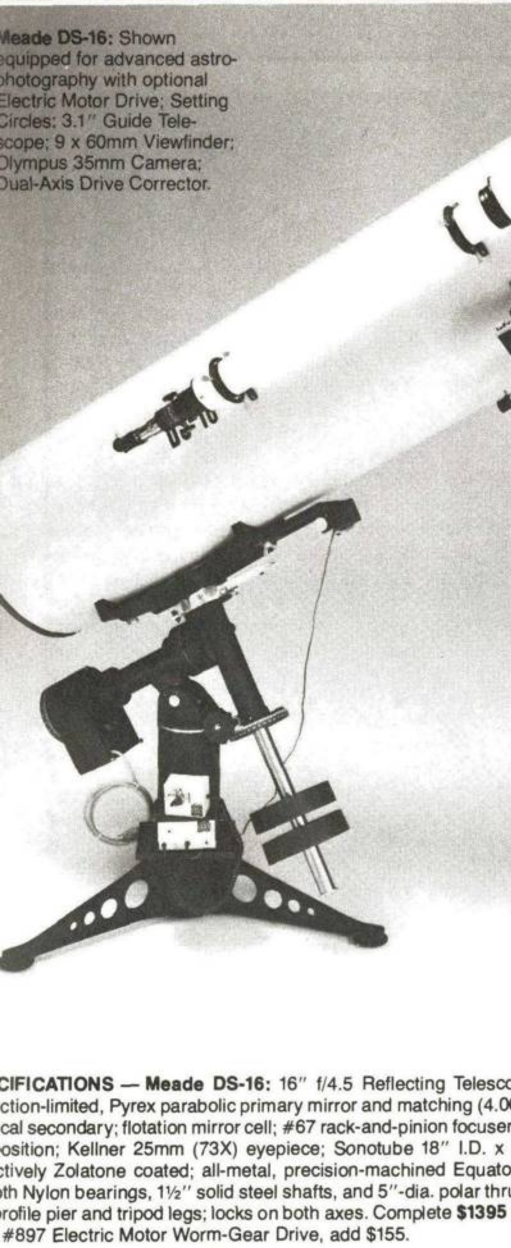
39—**MICROMETER RETICLE**—Full-field scale for accurate measurements of double star separations, planetary angular diameters, etc. Interchanges with standard 4-line reticle of Item (38) above . . . . **$19.50 ppd.**

40—**ERECTING PRISMS** — Fully coated Porro prisms. Invert the astronomical image for terrestrial observations with astronomical telescopes. **1¼" O.D. . . . $31.50 ppd.; .965" O.D. . . . $29.95 ppd.**

DIAGONAL PRISMS—Optical-quality right-angle prisms, fully coated.

41—**Model 915:** Fits .965" focusers, accepts .965" eyepieces . . . **$24.95 ppd.**
42—**Model 917:** Hybrid diagonal — fits .965" focusers, accepts 1¼" O.D. eyepieces . . . . **$26.95 ppd.**
43—**Model 918:** 18mm clear aperture. Fits 1¼" focusers, accepts 1¼" eyepieces . . . . **$24.95 ppd.**
44—**Model 918A:** 30mm clear aperture. Fits 1¼" focusers, accepts 1¼" eyepieces. Enlarged aperture increases field at low power . . . . **$28.95 ppd.**

Meade® 10″ f/4.5 and 16″ f/4.5 DEEP-SPACE Telescopes



Meade DS-16: Shown
equipped for advanced astro-
photography with optional
Electric Motor Drive; Setting
Circles; 3.1″ Guide Tele-
scope; 9 x 60mm Viewfinder;
Olympus 35mm Camera;
Dual-Axis Drive Corrector.

"The Meade DS-16 is definitely the best astronomical investment I've ever made."

Since their introduction in early 1982, Meade 10″ and 16″ Deep-Space Telescopes have revolutionized the visual observation and astrophotography of Deep-Space objects by the serious amateur. Hundreds of these incredible instruments are now in use throughout the World, with observers continuing to report visual detail never before seen in their experience through amateur-owned equipment.

By combining giant apertures with fast f/4.5 photographic focal ratios, Meade Deep-Space Telescopes permit the capture on film of elusive nebular and galactic detail in 5-to-15 minute exposures—exposure times so short even a beginner can obtain exciting results. Visually, the Meade DS-10 and DS-16 enable observation of subtle blue-green colorations in such objects as the Great Nebula in Orion (M42); inspection of dust lanes in spiral galaxies such as M51 and M101; resolution to the core of the Hercules globular cluster (M13). And, with their rock-solid equatorial mounts, Meade Deep-Space Telescopes virtually eliminate the bothersome backlash and wobble so detrimental to serious observing.

Read what DS-10 and DS-16 owners are saying:

"Observing with the DS-10, I can not praise it enough. For the price, I don't believe it can ever be beaten. Even lunar observing has been fantastic. On deep-sky objects the sky is literally the limit. The DS-10 is also very suitable for double star observations. The wide field of view gives beautiful framing of double stars at lower powers. If you compare the DS-10 to any other scope of equal price, the DS-10 comes out far ahead. It is and will continue to be a pleasure to use."

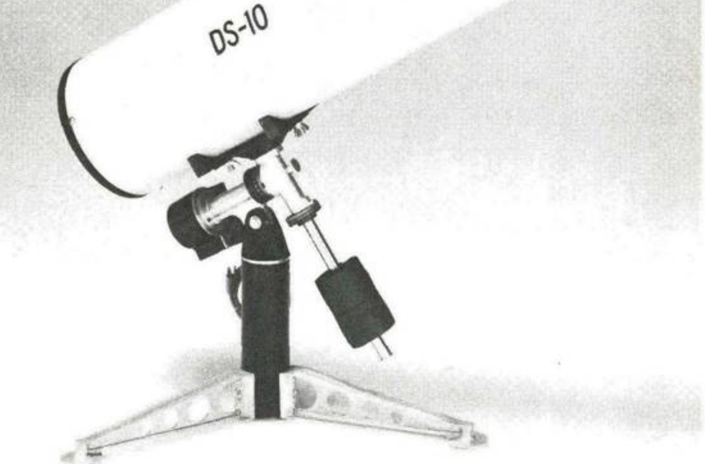
—T. Bosler, Douglasville, PA

"I'm writing to let you know how much I enjoy my DS-16. I can finally see the detail and structure in galaxies that I've only dreamed of before. Last February I got carried away and observed 98 galaxies in one night! M101 is fantastic. The spiral arms seem to go on forever and more than a dozen HII regions are evident. The Meade DS-16 is definitely the best astronomical investment I've ever made."

—B.J. Williams, Houston, TX

CIFICATIONS — **Meade DS-16:** 16″ f/4.5 Reflecting Telescope. With null-figured,
ction-limited, Pyrex parabolic primary mirror and matching (4.00″ M.A.) 1/10-wave flat
cal secondary; flotation mirror cell; #67 rack-and-pinion focuser at convenient observ-
osition; Kellner 25mm (73X) eyepiece; Sonotube 18″ I.D. x 68″ long, sealed and
ctively Zolatone coated; all-metal, precision-machined Equatorial Mount, with ultra-
th Nylon bearings, 1½″ solid steel shafts, and 5″-dia. polar thrust surface; rock-solid,
rofile pier and tripod legs; locks on both axes. Complete **$1395** FOB Costa Mesa, CA.
#897 Electric Motor Worm-Gear Drive, add $155.

CIFICATIONS — **Meade DS-10:** 10″ f/4.5 Reflecting Telescope. With null-figured,
ction-limited Pyrex parabolic primary mirror and matching (2.60″ M.A.) 1/10-wave flat
cal secondary; #67 rack-and-pinion focuser at convenient observing position; Kellner
n (46X) eyepiece; Sonotube 12″ I.D. x 46″ long, sealed and attractively Zolatone
d; all-metal, precision-machined Equatorial Mount, with ultrasmooth nylon bearings
″ solid steel shafts; rock-solid, low-profile pier and tripod legs; locks on both axes.
plete **$579.95** FOB Costa Mesa, CA. With #787 Electric Motor Drive, add $75.



Meade DS-10: With optional
Electric Motor Drive; Setting
Circles; 6 x 30mm Viewfinder.

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U.S.A. and Canada. For the name and address of your nearest
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ASTRONEWS

Hey, You! Wanna Be an Astronaut?

The first of what will become an annual selection of Space Shuttle astronauts by the National Aeronautics and Space Administration will commence later this year.

NASA anticipates openings for six pilots and six mission specialists in this selection. Pilot astronauts are responsible for the control of Space Shuttles during launch, re-entry, and other required maneuvers and for maintenance of flight systems. Mission specialists' responsibilities include management and operation of Shuttle systems that support payloads during flight.

Applications from civilians will be accepted between October 1 and December 1, 1983. Selections will be made in the spring of 1984, and successful candidates will report to work that summer.

Minimum qualifications for pilot astronauts are:

- A bachelor's degree from an accredited institution in engineering, biological or physical science, or mathematics.
- At least 1,000 hours time as pilot in command of high performance jet aircraft. Flight test experience is highly desirable.
- Ability to pass a NASA Class I space flight physical examination, which is similar to military and civilian flight physicals.
- Height between 64 and 76 inches.

For mission specialists, minimum qualifications are:

- A bachelor's degree from an accredited institution in engineering, biological or physical science, or mathematics.
- Degree must be supplemented by at least three years of related professional experience. An advanced degree is desirable and may be substituted for the experience requirement.
- Ability to pass a NASA Class II space flight physical examination, which is similar to military and civilian flight physicals.
- Height between 60 and 76 inches.

NASA has an affirmative action program goal of including qualified minorities and women among the newly selected candidates.

The number of candidates recruited in subsequent selection periods will vary depending upon mission requirements and the rate of attrition in the existing astronaut corps.

Write to: Johnson Space Center, Houston, TX 77058.

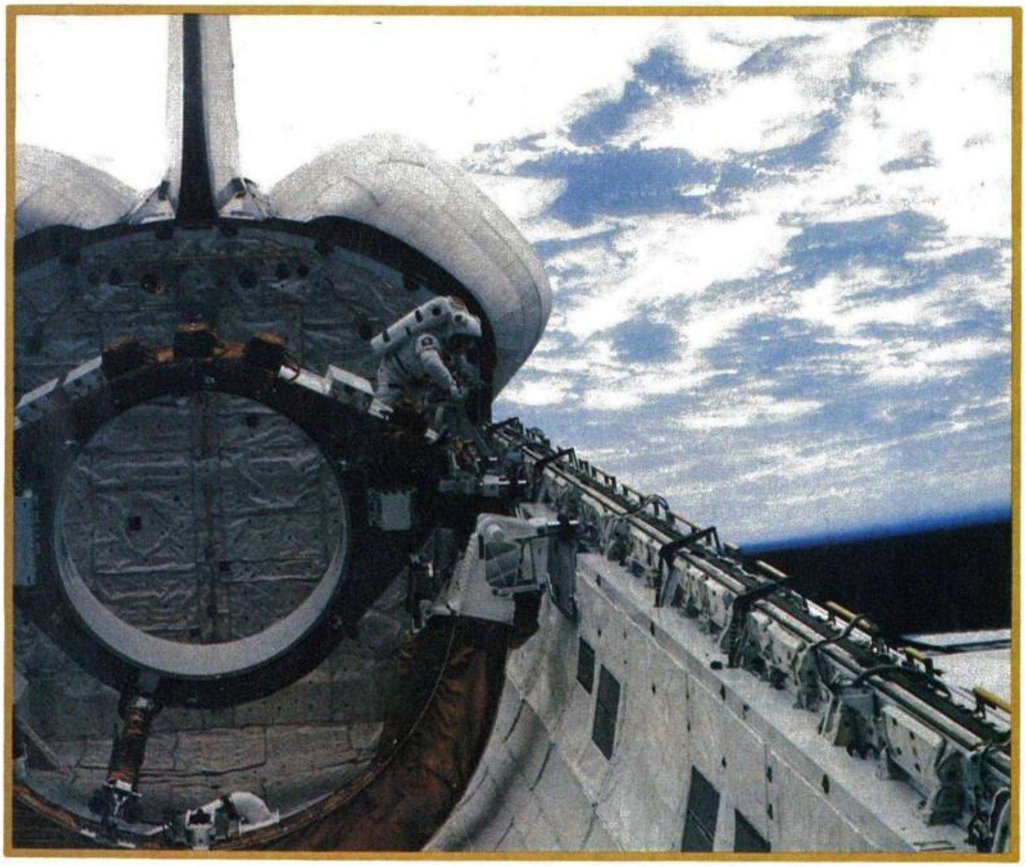
Why Do Radio Jets Bend?

Two Indian scientists recently proposed a new explanation for the S-shaped distortions found in the radio jets of some relatively dim, yet physically large, elliptical galaxies. Writing in *Nature*, Gopal-Krishna and S.M. Chitre of the Tata Institute of Fundamental Research in Bombay point to the difficulty of explaining how such jets can remain straight as they extend for hundreds of kiloparsecs, and then suddenly bend. One explanation has been precession — but if these distortions were caused by a precessing source object at the galaxy's center, "implausibly low gas densities" for the intergalactic medium would be required for the jet to remain straight for so great a distance. Another explanation — that the jets are slamming into material in a gaseous galactic halo — doesn't work because the distortions occur much too far from the galaxy for a halo to be the culprit.

The authors then point out that "recently, deep optical photographs of a few nearby ellipticals have revealed the existence of multiple shell fragments . . . [which] may be formed during the merger of a disk galaxy with a massive elliptical." These partial shells are chiefly made up of stars, together with a small amount of gas, and orbit typically a few hundred kiloparsecs out from the galactic center. The scientists propose that the outflowing beams may have sufficient energy to penetrate partway into the shell before they are slowed and then swept "downstream" by the rotating shell — thus producing the S-shaped bends. Lending weight to the argument is the fact that these bent jets are found only in relatively isolated galaxies, where a "less disturbed environment [would be] more conducive to shell formation."

Kinks and bends found in the more highly powered jets from objects such as quasars — jets powerful enough to chop through any likely shell — may be accounted for by a similar type of interaction with the more massive spiral arms of a galaxy surrounding the quasar or perhaps with another galaxy altogether.

The scientists conclude by recommending a search for shell fragments near the point where jet deflection occurs, suggesting that "shell properties would also provide a valuable diagnostic probe of the physical parameters of the beam fluid dynamically interacting with the shells." *Donald F. Robertson.*



NASA

Congress Considering a Space Commerce Act

The Space Commerce Act, a bill now before the Science and Technology Committee of the U.S. House of Representatives, would give the Department of Commerce jurisdiction over the licensing of private space launches in the United States.

The act would clear up the current legal ambiguities that required a private firm — Houston-based Space Services Inc. — to deal with at least five different federal agencies before it received authority, in September 1982, to launch its Conestoga I rocket from an island off the Texas coast (see AstroNews, December 1982). To conduct the test, the company had to get clearances from the Federal Aviation Administration, the U.S. Navy, the State Department, the Federal Communications Commission, and the National Aeronautics and Space Administration.

The new bill, H.R. 1011, would officially make the Commerce Department responsible for receiving, processing, and validating applications for licenses to launch space vehicles. To get a license, an applicant would have to prove that it has adequate liability insurance,

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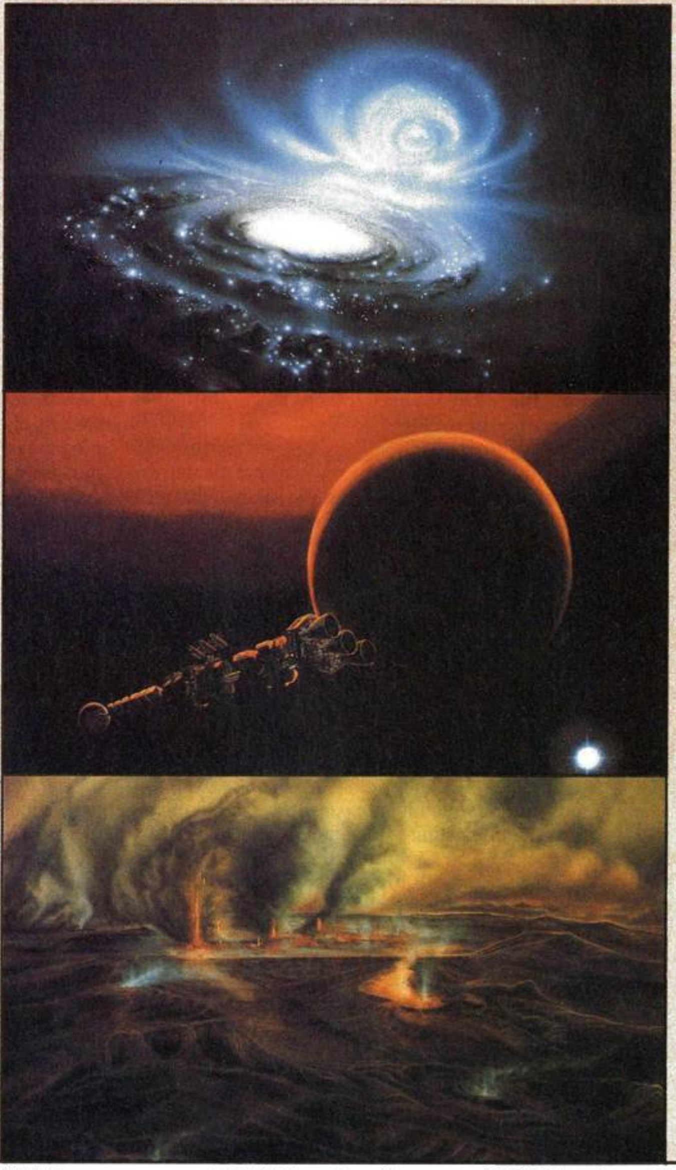

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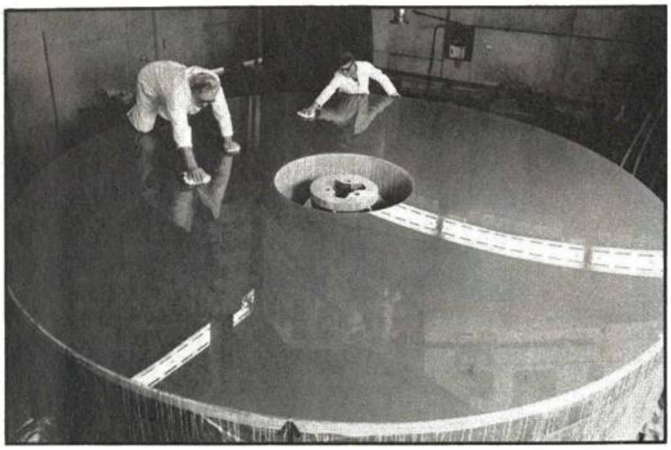


Technicians polish the giant 17-ton primary mirror, the major component in the William Herschel 4.2 meter telescope to be sited at the new international observatory on La Palma in the Canary Islands. When fully operational in 1986, the British optical telescope — 60 feet (18 meters) high and weighing 190 tons — will be one of the largest in the world. Using satellite communication links, it will be controlled from the Royal Greenwich Observatory in southern England.

that the proposed payload and launch site will not pose undue risk to public safety or national security, and that obligations of the U.S. government under international treaties and agreements are met. The Commerce Department would also approve any payload before issuing a license.

The act would create a nine-member Commercial Space Study Commission made up of "individuals qualified as expert in the development of commercial space activities." (The FAA, the FCC, and NASA could be represented by one member each, however.) The Commission would conduct a year-long study of the direction of future government involvement, support, and regulation of private sector commercial activity in space. Based on its findings, the Commission would recommend appropriate legislative action to Congress.

Since the successful test flight, Space Services Inc. has been planning an orbital flight within the next two years. SSI officials say that several oil companies have expressed interest in using their launch vehicles to put Earth-sensing satellites in low orbits. And at least one other firm is considering using a satellite in a low orbit to receive messages as it passes over one area of the Earth and deliver them as it passes over another area.

Besides Space Services Inc., as many as six firms are reportedly considering providing similar privately funded satellite launching services. *Ray Grasshoff.*

Spiral Galaxies and New Stars

For years, astronomers have argued about the forces responsible for the creation and maintenance of a spiral galaxy's pinwheel shape. If spiral arms carry the same material through each revolution, they should disappear after only a few galactic rotations. But spiral galaxies make up roughly 25 percent of all known galaxies — and they've existed much longer than the time required for several galactic rotations. So some force must either maintain spiral arms or constantly generate new ones.

One idea, proposed in the 1960s, suggests that a spiral-shaped gravitational potential underlies all spiral galaxies. Dust and gas collect in this gravitational "groove" and generate galaxy-wide standing waves in the interstellar medium. Dust and gas entering the groove become violently compressed, form stars, and maintain spiral arms rich in gas, dust, and new stars.

The key to spiral arms is the massive, young, short-lived stars that compose them. While high-mass stars do not make up the bulk of a galaxy's stellar population, they do provide most of the light. Since massive stars only shine for a few million years, they don't live long enough to drift far from the gas clouds that spawned them. Thus explanations of spiral arms must also discuss the formation of stars (see "To Sculpt the Galaxies," ASTRONOMY, January 1983).

According to one suggestion, stars form when gas clouds randomly collide or when an isolated cloud undergoes spontaneous contraction. Again, compression of the clouds results in sporadic star formation. In another mechanism, the stellar wind from a massive star or the concussion of a nearby supernova compresses interstellar clouds and leads to the creation of stars — each new stellar generation creates its successors. There is strong observational support for this sequential star formation mechanism.

In both cases, the patch of newly created stars will be stretched into a spiral arm by the differential rotation of the galaxy. Which of these processes is most important in maintaining spiral arms? In an effort to answer this question, Ohio State University physicist Michele Kaufman examined the distribution of massive stars in the spirals M-33, M-83, and our own Galaxy.

Unfortunately, massive stars may be obscured by interstellar gas clouds and frequently appear in groups, complicating a count of individual stars. So Kaufman and co-worker Kenneth Rumstay used ionized hydrogen regions and the radio emission from certain parts of the galaxies to determine the abundance of high-mass stars.

Their results indicate that large clusters of high-mass stars are likely to be the result of spiral density waves, while smaller complexes owe their existence to sporadic or sequential mechanisms. But an unanswered piece of the puzzle remains: What determines the creation of large star complexes instead of small ones? According to Kaufman, the determining factor may be the mass of the cloud out of which the stars form — clouds of higher average mass would form more stars.

Volcanic Moon

Ancient geological forces finally crack open fractures in the lunar crust. Magma, long held in check, slowly wells toward a distant surface. Thin sheets of molten rock, still glowing beneath a cooling crust, spill over the cold remains of far older lava flows. And in the process, they cover the bright rays of a small crater on that great "sea" of lava that men would one day name Oceanus Procellarum.

Lichtenberg crater, which can be found at 32° north and 68° west on a map of the lunar nearside, appears at first glance to be a perfectly ordinary crater with a singularly unspectacular system of rays. Yet Peter H. Schultz of NASA's Lunar and Planetary Institute and P.D. Spudis of Arizona State University's Department of Geology believe this small crater may provide powerful evidence that the Moon has undergone relatively recent volcanism.

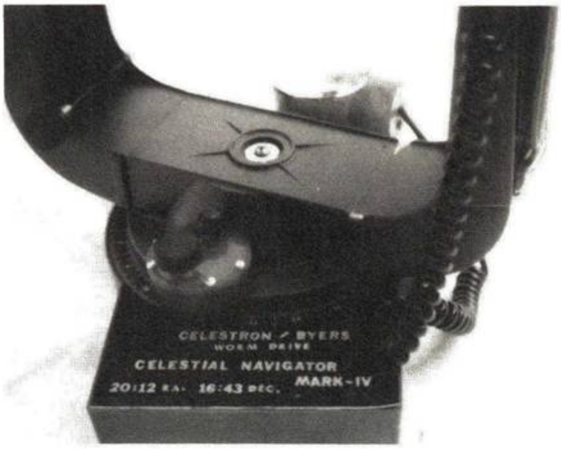
The bright rays that streak many parts of the Moon's visible surface are rather fragile structures, consisting of thin blankets of debris thrown outward during the impacts that created the craters from which they radiate. These ray blankets are rapidly (by lunar standards) darkened by the ever-present fall of interplanetary dust and destroyed by numerous small impacts. The actual rate is determined by comparing its size with the thickness of the debris, which is in turn determined by the size of the source crater. In theory, therefore, the age of a lunar crater may be roughly determined by comparing its size with the preservation of its rays.

Lichtenberg appears to be about the same age as Copernicus, which would make it only 900 million years old. Yet Lichtenberg's rays, and a part of its outer ring-wall, are covered by a number of thin lava flows.

To have buried Lichtenberg's rays, the lava in question must have erupted since Lichtenberg was formed — or about a billion years *after* lunar volcanism is thought to have ended. Schultz and Spudis suggest that such young lava flows may have been overlooked until now because earlier studies reflected "statistics from broad areas and different horizons, thereby combining and overestimating the age of the youngest units."

Other findings of theirs concern the earlier parts of lunar history. The researchers think there may have been a distinct period of volcanism before the currently recognized beginning of lunar activity. As evidence, they point to the fragments of volcanic basalts that are incorporated in the ancient lunar highlands rocks, the oldest rocks on the Moon. Calculations indicate that there are more such fragments than can be accounted for by debris from later impacts, and at least part of the material must be indigenous. In addition, these early volcanic fragments appear to be connected with basins created by major impacts; the researchers believe that "volcanic flows constituted at least a part of the target for these impacts."

GREAT NEWS



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ASTRO NEWS

But were all of these early lava flows completely destroyed by subsequent impacts? Might they somehow be detected beneath the modern surface? Schultz and Spudis think that concentrations of craters surrounded by halos of dark material may reveal just such ancient maria. The halos may consist of old mare material excavated by an impact that dug down through the overlying highland rocks and scattered the underlying material across the new surface. If this is true, then the distribution of dark-halo craters may "map" the ancient maria.

Most of these craters are on the lunar farside, possibly because debris from the Imbrium and Oriental impacts buried the nearside's ancient flows too deeply to be excavated by later impacts. Other haloed craters hint at very "ill-defined" rings of ancient lavas that surround such younger maria as Mare Smithii and Mare Crisium.

If confirmed, this may support theories which postulate that the weight of lava filling ancient impact basins created tensions that reopened deep-seated fractures. Younger lava would then have spilled out to refill the inner portions of the basins, creating the great "seas" we observe today. *Donald F. Robertson.*

A Peek at Starbirth

Stars are created all the time in the cool, dense molecular clouds of our Galaxy. Unfortunately, the dusty clouds in which stars form also obscure newborn suns from terrestrial eyes. A starcloud's veil usually limits astronomers to the infrared and radio wavelengths able to penetrate it, but a researcher working in Chile may actually have glimpsed the birth of a star.

John Graham of Cerro Tololo Inter-American Observatory near La Serena, Chile, recently detected a star so young that it has just now shed its dust-gas cocoon. "The process is thought to take place over a period of about 10,000 years," remarks Graham.

A star forms from a clump of gas and dust. The clump gains mass as its gravitation draws more matter into it. The increased mass adds to the strength of its gravitational attraction, thereby drawing more material into the clump — runaway accretion begins. As the clump gets more massive, it collapses into itself and grows progressively more dense. Temperature increases along with the density until the proto-star's core reaches a temperature of about ten million degrees. At this point, the core's hydrogen fuses into helium and the proto-star becomes a star.

When a proto-star turns on its nuclear furnace, powerful streams of charged particles — a stellar wind — blow from its surface. Astronomers do not yet know what powers the energetic wind of a newly formed star, but it is sufficiently violent to break through the surrounding envelope of gas and dust. The cloud is sloughed off, and the new star becomes visible from Earth.

It was just this event that Graham witnessed in Chile while studying some luminous cloudlets called Herbig-Haro (HH) objects. Closely associated with regions of star formation, HH objects are either fragments ejected by young stars or ambient gas shocked to flourescence by stellar winds.

On March 16, Graham noticed a bright star at the northeast tip of an object designated HH 57. The star was not visible on Cerro Tololo photographs of the same object taken in 1976; Hale telescope plates taken in 1962 also fail to show the star. According to Graham, Australia's Siding Spring Observatory photographed the region in 1980 and captured the star's image. "But it was much fainter than it is today," notes Graham, "and therefore was not noticed."

ASTRO CALENDAR

September 17	**Astronomy Club of Akron OTAA Convention.** University of Akron, Akron, Ohio. Contact: Phil Hegenderfer, 5070 Manchester Rd., Akron, OH 44319. Phone (216) 644-0230.
September 30-October 2	**Astrofest '83.** Sponsored by the Chicago Astronomical Society. Contact: Astrofest, P.O. Box 596, Tinley Park, IL 60477.
October 1	**Astro-Assembly.** Seagrave Observatory, Peeptoad Rd., North Scituate, Rhode Island. Sponsored by Skyscrapers, Inc. Contact: Gerald Dyck, 418 High Hill Rd., North Dartmouth, MA 02747.
October 8	**Telescope User's Clinic.** Sponsored by the Western Observatorium. Rio Hondo College, Whittier, California. Contact: Western Observatorium, 13215 E. Penn St. #411, Whittier, CA 90602. Phone Bob Ferguson at (213) 795-4181.
October 14-16	**Custer Institute's Astronomy Jubilee.** Southold, Long Island, New York. Contact: Warren E. Hamburger, President, Custer Astronomy Club, Main Bayview Rd., Southold, Long Island, NY 11971. Phone (516) 765-2626.
October 17-20	**15th Annual Meeting of the Division for Planetary Sciences of the American Astronomical Society** (professional meeting). Sheraton Conference Center, Ithaca, New York. For information about travel and accommodations, contact: Joseph A. Burns, Space Sciences Building, Cornell University, Ithaca, NY 14853.
October 21-23	**AAVSO Fall Meeting.** Nantucket, Massachusetts. Host institution, Maria Mitchell Observatory. Contact: Janet A. Mattei, AAVSO, 187 Concord Ave., Cambridge, MA 02138. Phone (617) 354-0484.
October 27-29	**Great Plains Planetarium Association Conference.** Hastings, Nebraska. Contact: Mitch Luman, J.M. McDonald Planetarium, 1330 N. Burlington, Hastings, NE 68910.
October 30	**"The Universe Unfolding,"** nontechnical public lecture series, Stanford University, Palo Alto, California. Sponsored by the Astronomical Society of the Pacific. Contact: Stanford Lectures, A.S.P., 1290 24th Ave., San Francisco, CA 94122.
August 1984	**6th World General Assembly of International Union of Amateur Astronomers.** Bologna, Italy. Contact: Dr. Luigi Baldinelli, c/o A.A.B., Casella Postale 1630 AD, 1-40100 Bologna BO, Italy.

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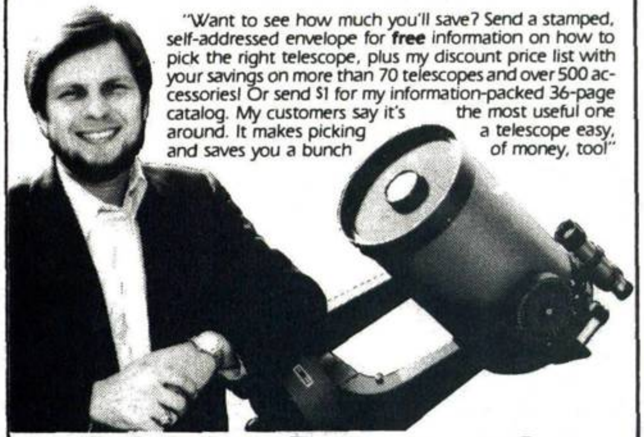

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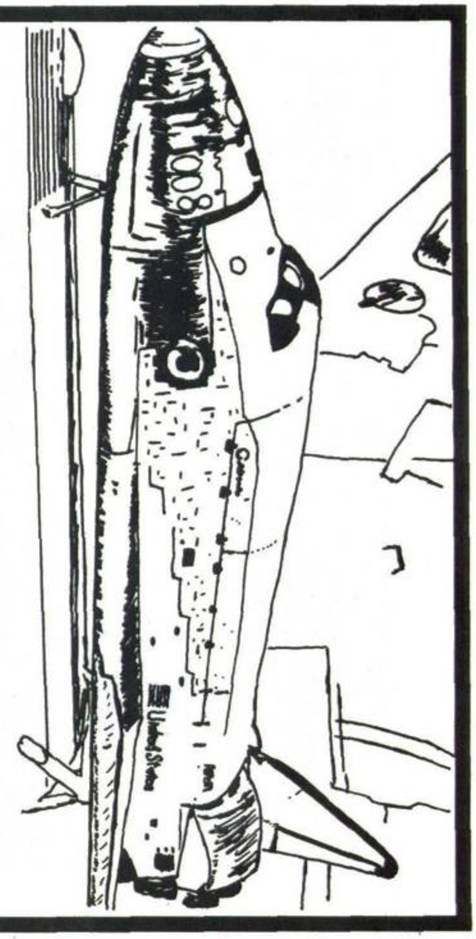

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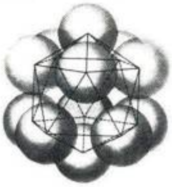

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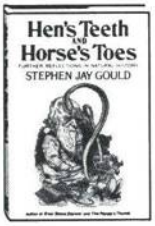

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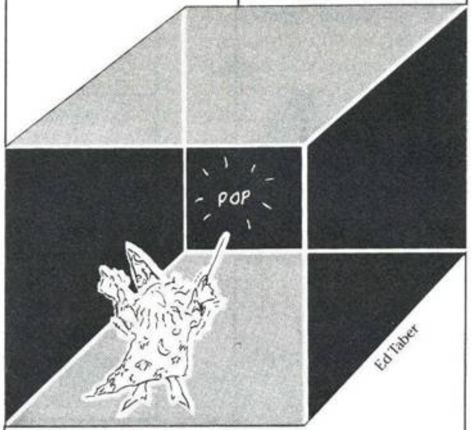

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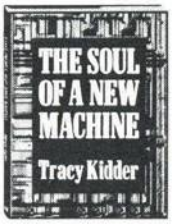

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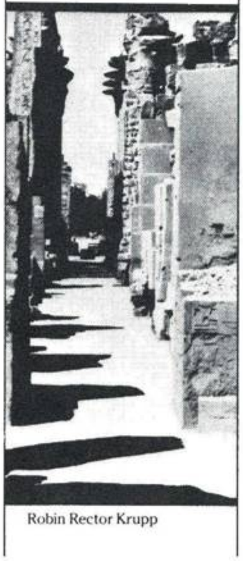

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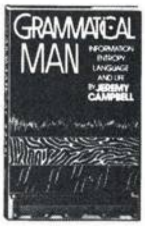

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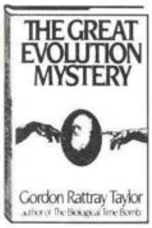
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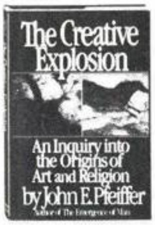
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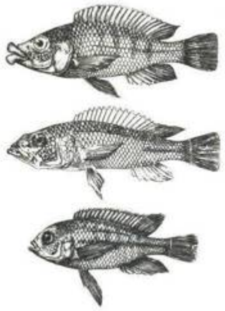

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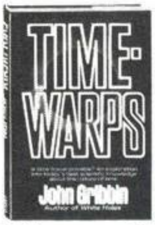
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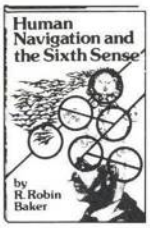
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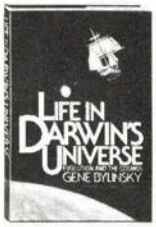
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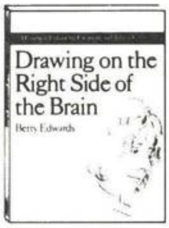
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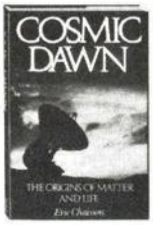
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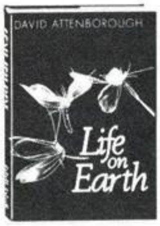
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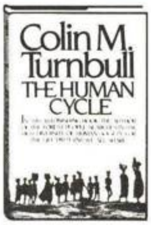
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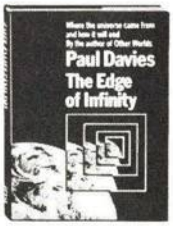
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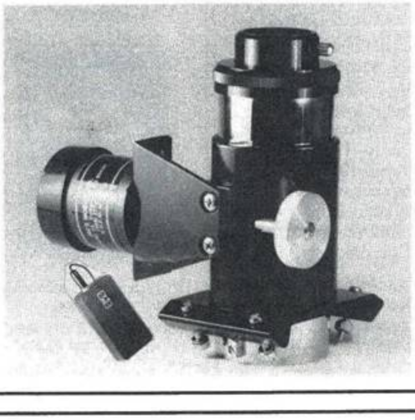

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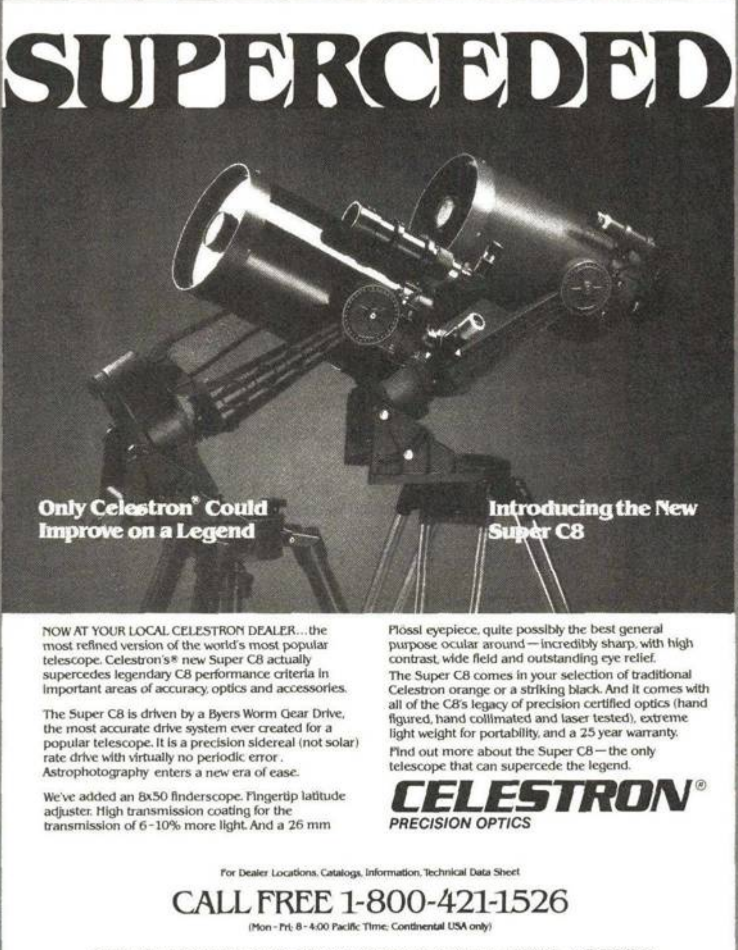

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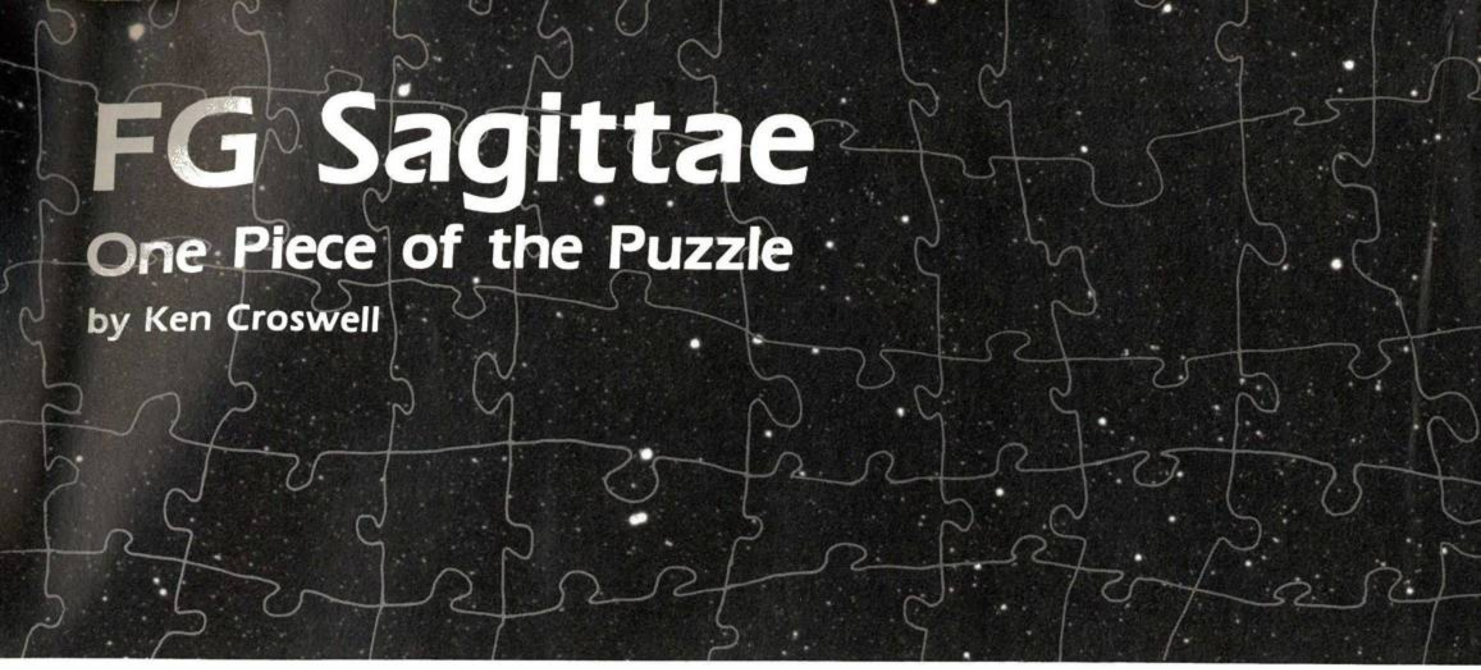


FG Sagittae

One Piece of the Puzzle

by Ken Croswell

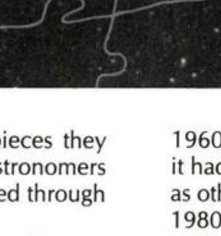
Jigsaw puzzles often boast the thousands of pieces they contain. But in attempting to understand the stars, astronomers face a puzzle with at least 200 billion pieces scattered through our Galaxy alone.

It's easy to build a puzzle once you've propped up its picture, constructed the border, and separated the pieces into several piles. But astronomers have no grand picture of the universe to use as a guide. And no one knows where the border between the possible and the impossible lies. Worse yet, classifying stars — dividing them into separate types — remains a difficult task.

The real breakthrough, both in puzzle-building and astronomy, comes in recognizing one of those "transition pieces" — a rare piece that connects the different pieces, providing a tremendous leap forward in constructing the whole picture. The star FG Sagittae is such a piece.

One of many variable stars in the tiny Milky Way constellation Sagitta, FG Sagittae appears to be nothing special at first glance. The very fact that its brightness changes — that it is a variable star — escaped detection until 1943.

After discovery, when astronomers checked old photographic plates, they noticed that the star had been brightening steadily since 1894, the first time the star had been photographed. In 1894 the star was at photographic magnitude 13.6, in 1950 it reached 11, and by 1960 it surpassed magnitude 10. It continued to brighten and apparently peaked, in 1968, around magnitude 9.5, declining slightly since. Superimposed on this startling, 44-fold brightness increase are small, irregular variations.



The light output was peculiar enough, but in 1960 Lick Observatory astronomer George Herbig noticed that the photographic image of FG Sge looked somewhat fuzzy. More powerful telescopes revealed a surrounding planetary nebula 36 seconds of arc in diameter. (Another astronomer, Karl Henize, had independently discovered the nebula in 1955.) Astronomers found that the nebula expands at 34 kilometers per second — a typical figure for planetary nebulae — and estimated that FG Sge was 8,100 light-years away. This distance implies a diameter of 1.4 light-years for the nebula and, coupled with the expansion rate, suggests that it was ejected about 6,000 years ago. Analysis of the nebular spectrum shows that the planetary nebula is completely normal, definitely associated with FG Sge, and many thousands of years old.

But the most exciting feature of FG Sge emerged when astronomers measured its spectrum. Spectrograms taken in 1955 indicated that the star was a supergiant of spectral type B4. By 1960, FG Sge had advanced to spectral type B9, and in 1967 it had reached A5! The star continued its rapid spectral change as other astronomers monitored it: in 1972 it was F6 and by late 1980 G9. These changing classifications indicated that FG Sge's surface temperature was plummeting — at times falling by more than 300° Kelvin in a single year. The star has expanded enormously, from 10 times the radius of the Sun in 1958 to 55 solar radii in 1973, after which it ceased expanding. FG Sagittae has changed from a hot blue star to a distended, moderate-temperature yellow star in just 20 years — the only star we know to be racing across the Hertzsprung-Russell diagram. Its luminosity and spectral type now place it near the instability strip, a region on the H-R diagram where the Cepheids dwell; some astronomers believe it may become such a pulsating star.

Ironically, the very thing that first called attention to FG Sagittae — its increase in brightness — now seems to be an illusion. FG Sge's total radiation output — its *bolometric magnitude* — hasn't changed over the years, but the wavelength where this radiation is most intense has increased. Since photographic films in the 1950s were more sensitive to light redder than that of a hot B-type star, they registered an increase in brightness as FG Sge cooled and reddened. From FG Sge's estimated distance of 8,100 light years, its absolute bolometric magnitude is about −4.2, about three magnitudes fainter than normal supergiants.

FG Sagittae tossed astronomers another surprise in the mid-1960s, when rare elements invaded its spectrum. Astronomers discovered that the abundance of singly ionized yttrium, zirconium, cerium, and other elements had increased by a factor of 25 between 1965 and 1972. The increase has since halted, but the abundances of these elements remain at abnormally high levels.

Where did these elements come from? New elements are created by two main processes in a star: the s-process and the r-process. The s-process (for "slow") occurs when relatively few free neutrons are available for capture by an atomic nucleus. A nucleus that catches a neutron will change to a different isotope of the original element, from one isotope of tin to another, for example. But if the newly formed nucleus is unstable, it will release an electron or positron in order to settle down, actually changing the nucleus from an isotope of the original element to a nucleus of another element. In our example, the original tin nucleus might turn into a nucleus of antimony. The s-process produces just about all the elements up to bismuth, and is thought to occur in red giants.

On the other hand, the r-process (for "rapid") requires a

much greater number of neutrons, so great that even unstable nuclei do not have time to decay before capturing another neutron. Since the neutron flux is so high, the r-process can generate nuclei too unstable for the s-process to synthesize. Astronomers believe that the r-process occurs within supernova explosions. The difference between the two processes is considerable — in the s-process it may take a century for a nucleus to capture two neutrons in succession, while nuclei involved in the r-process are bombarded by millions of neutrons every second! Scientists have calculated the elements favored by each process, and all of the elements that suddenly appeared in FG Sge's spectrum are formed in the s-process.

FG Sagittae can no longer be regarded as just another little-known variable in a tiny constellation. Its light curve, planetary nebula, and bizarre spectral changes all betray important events taking place deep inside the star. Astronomers *know* they have something here — they just aren't sure what it is.

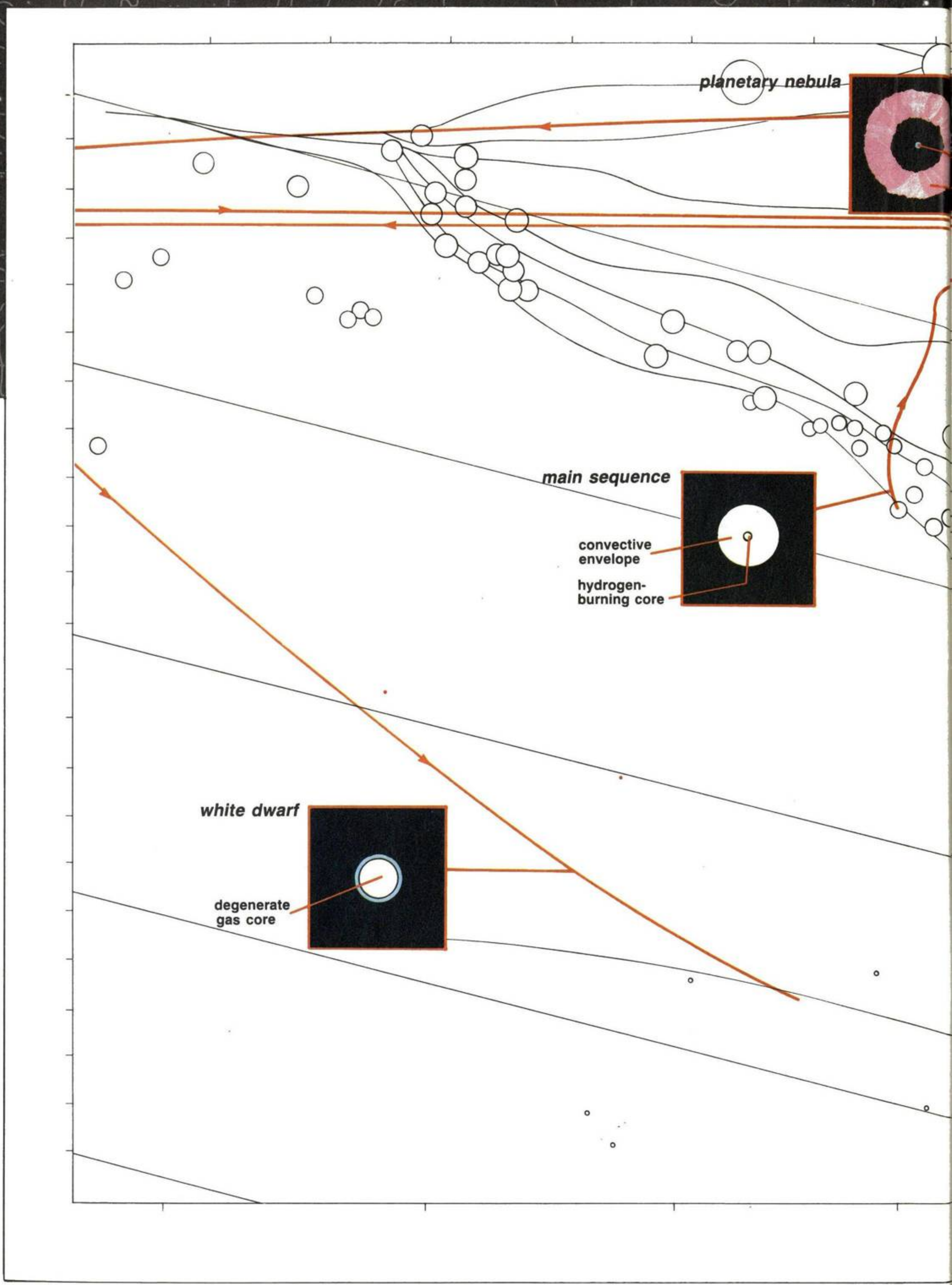
One way to understand this intriguing variable is to examine the evolution of stars in its mass range — about four times that of the Sun. When a star turns on its hydrogen fusion furnace, it starts to blow away the dust-gas cocoon in which it formed. Irregular changes in brightness and a powerful stellar wind mark this phase of the star's evolution, typified by the young variable T Tauri. Within a million years, the star moves to the main sequence — the portion of the Hertzsprung-Russell diagram occupied by stars whose main source of energy is the fusion of protons within their cores. Its brightness decreases as it descends to the main sequence, but its surface temperature rises. Fusion of hydrogen nuclei within the core produces an "ash" of helium nuclei, which collects in the center of the core. Over the next 60 million years, the central part of the star slowly runs out of its hydrogen fuel, burning only in a shell around the core; the helium core contracts and heats up. The star's outer layers expand, its surface temperature lowers, and its luminosity decreases — it leaves the main sequence to become a red giant.

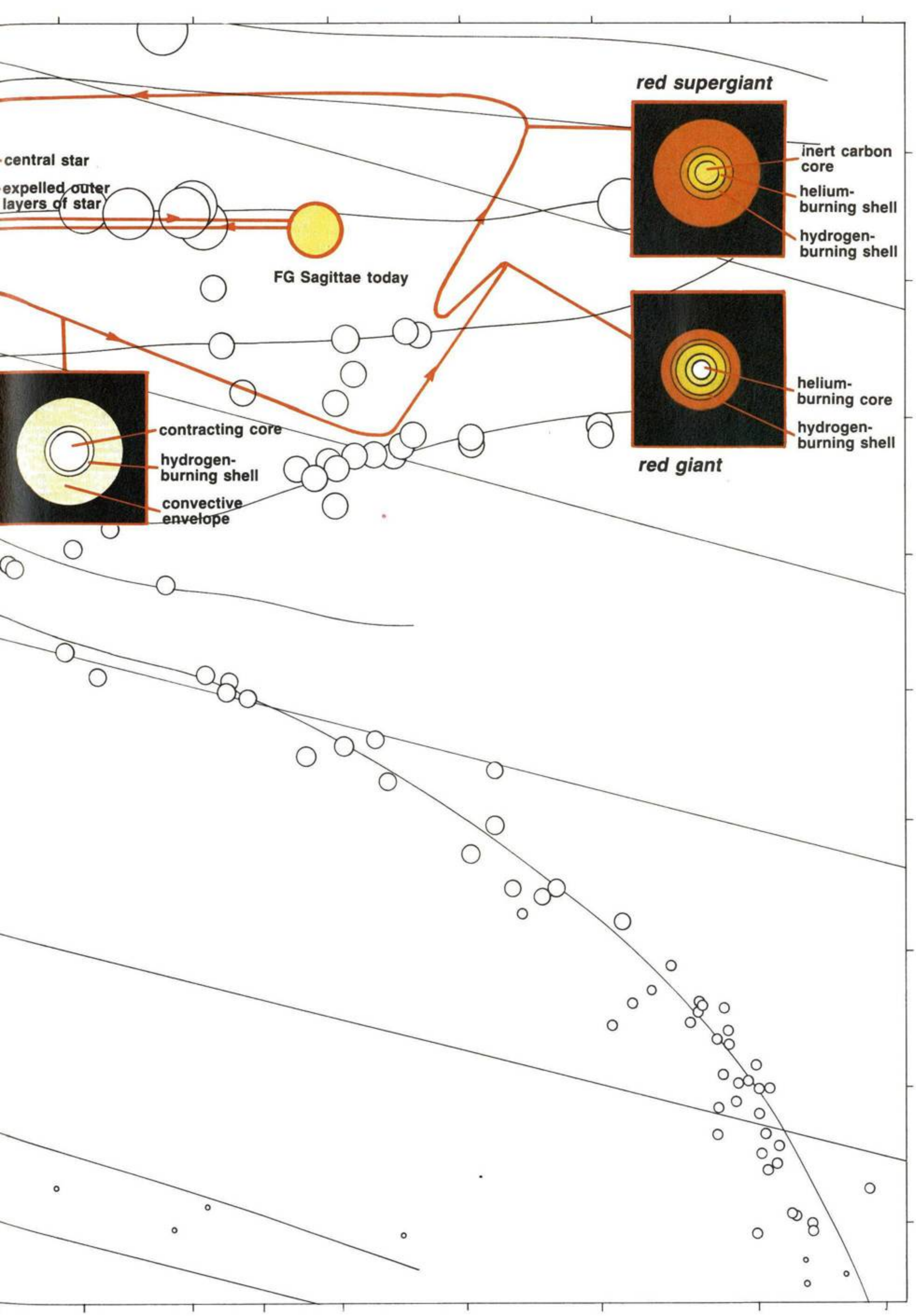
Eventually, the star's core of helium ash becomes hot enough to undergo nuclear fusion — core helium burning has begun. Helium fusion generates heat within the core, but the extreme density of the material prohibits the core from expanding and cooling. In classical physics, the pressure from a gas is governed by both its density and its temperature. At the high densities of a red giant's core, however, the pressure from the gas no longer responds to increases in temperature, but only to increases in density. Physicists call such a gas *degenerate*. Unable to compensate for the increased heat within, the temperature of the core climbs. Helium fuses at a faster rate, dumping still more heat into the core and raising its temperature, which forces the rate of the thermonuclear reactions to increase further. In a matter of hours, the core's temperature increases so much that the gas in the core is no longer degenerate. The transition from a degenerate gas to one that obeys the laws of classical physics allows the core to expand violently and cool, compensating for its increased temperature. This runaway thermonuclear reaction is known as the *helium flash*; it occurs at the tip of the red giant region. The star's surface temperature increases, thus becoming bluer.

FG SAGITTAE'S CHANGING SPECTRUM

Year	Spectral Type	Effective Temperature (degrees Kelvin)
1955	B4	10,000
1960	B9	9,700
1965	A3	8,700
1966	A3 to A4	8,500
1967	A5	8,300
1968	A3	8,700
1969	F0	7,500
1970	F2	7,200
1970	F3 to F6	6,500
1971	F4	6,300
1972	F6	6,300
1974	G0	5,800
1975	G2	5,500
1977	G3 to G4	5,300
1979	G8 to G9	5,000
1980	G8 to K0	5,000

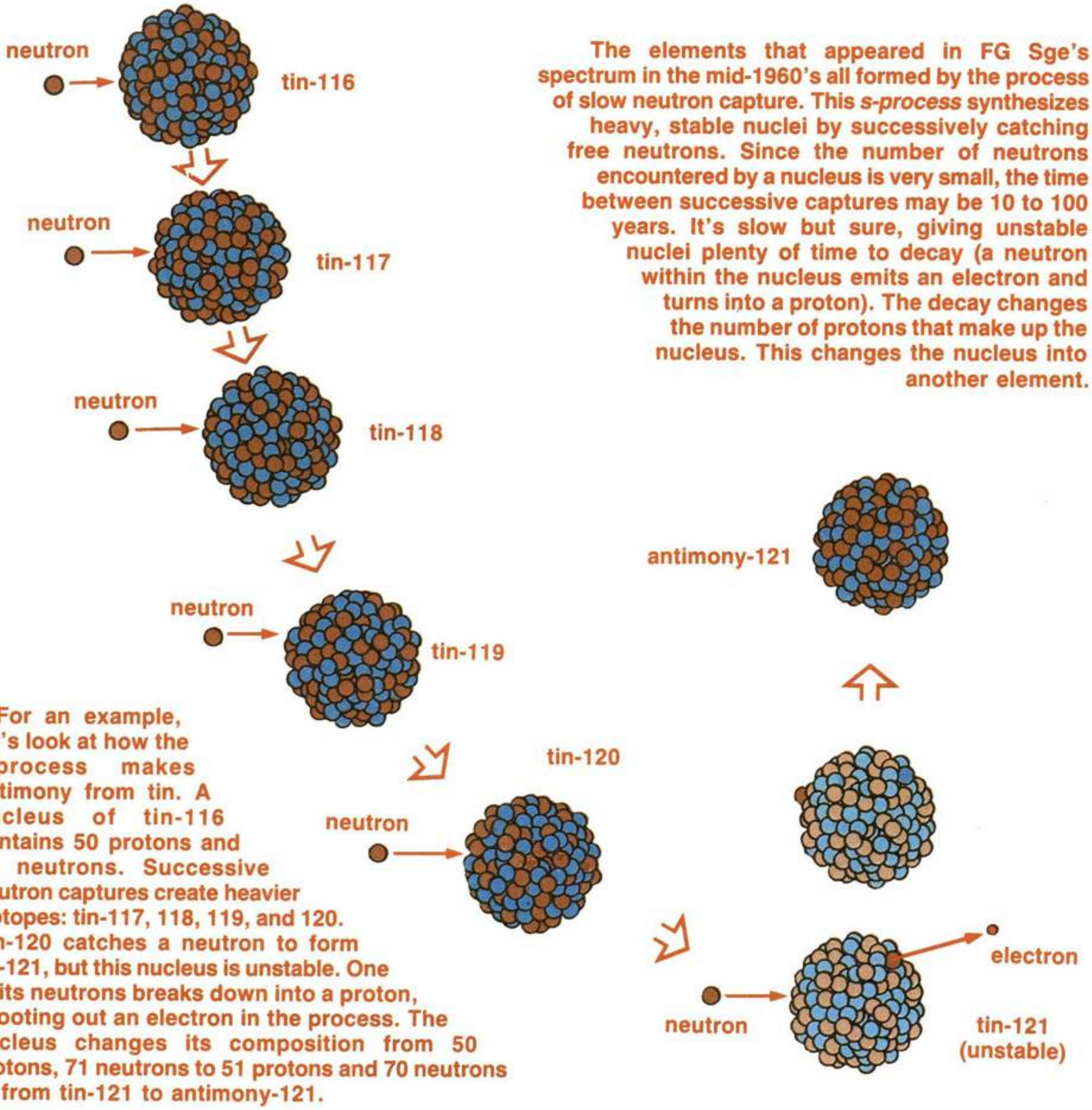
Inside the star, hydrogen still burns into helium in an outer shell around the core, where helium fuses to form carbon and oxygen. In about 10 million years, when the core again exhausts its fuel, helium burns only in a layer surrounding the carbon-oxygen core. Surface temperature decreases, and the star reddens again. Hydrogen stops burning in the outer shell as the star cools and returns to the low-surface-temperature, high-luminosity regime of the red giant. Hydrogen re-ignites in a thin layer outside the helium-burning shell, and the star again reaches the tip of the red giant branch. We now have a double-shell red giant: hydrogen burns into helium in an outer shell and helium fuses into carbon and oxygen in an inner one. Helium shell burning is, however, unstable, so the star may suffer occasional helium flashes.


planetary nebula
main sequence
convective envelope
hydrogen-burning core
white dwarf
degenerate gas core


red supergiant
central star
expelled outer layers of star
FG Sagittae today
inert carbon core
helium-burning shell
hydrogen-burning shell
helium-burning core
hydrogen-burning shell
red giant
contracting core
hydrogen-burning shell
convective envelope

the s-process of transmutation

The elements that appeared in FG Sge's spectrum in the mid-1960's all formed by the process of slow neutron capture. This *s-process* synthesizes heavy, stable nuclei by successively catching free neutrons. Since the number of neutrons encountered by a nucleus is very small, the time between successive captures may be 10 to 100 years. It's slow but sure, giving unstable nuclei plenty of time to decay (a neutron within the nucleus emits an electron and turns into a proton). The decay changes the number of protons that make up the nucleus. This changes the nucleus into another element.



For an example, let's look at how the s-process makes antimony from tin. A nucleus of tin-116 contains 50 protons and 66 neutrons. Successive neutron captures create heavier isotopes: tin-117, 118, 119, and 120. Tin-120 catches a neutron to form tin-121, but this nucleus is unstable. One of its neutrons breaks down into a proton, shooting out an electron in the process. The nucleus changes its composition from 50 protons, 71 neutrons to 51 protons and 70 neutrons — from tin-121 to antimony-121.

Once at the red giant tip, the star may eject its hydrogen-rich envelope into space and create a planetary nebula. Astronomers are not certain how the envelope is emitted, but helium shell flashes are one possible cause. In any case, the newly bared, hot inner portion of our red giant becomes the nucleus of a planetary nebula.

Since this stellar remnant is extremely hot, the star moves to the high-surface-temperature, high-luminosity region of the H-R diagram. The star's high temperature causes the ejected gas to glow. Although the star may still generate heat through thermonuclear reactions, it eventually fades into a cool, faint white dwarf.

How does FG Sagittae fit into this scheme? Initial studies showed that its atmosphere was expanding at about 70 kilometers per second, and the first theory advanced to explain FG Sge's peculiar behavior was that the star was ejecting a second planetary.

But this idea ran into trouble. First, the atmosphere stopped expanding in the mid-1960s. Second, although they differ, the various explanations for the formation of planetary nebulae generally agree that only red giants expel their envelopes — and FG Sge was once a hot *blue* star. Finally, the ejection of a second planetary nebula should produce a variety of effects that are not observed.

Another proposal suggests that FG Sagittae was a three-solar-mass double-shell red giant hit by a series of helium shell flashes. In this model, a very energetic flash 6,000 years ago kicked off the planetary nebula we see today. The helium shell flashes produced s-process elements that have only now been brought to the surface by convective mixing. Right now, FG Sge's spectrum looks similar to those of S-type stars whose spectra contain strong lines of barium. Similar to cool, red, M-type giants, type S stars exhibit lines of zirconium oxide in their spectra. Barium stars are, in turn, similar to S-type stars, although they resemble late G- and K-type giants. Both types of stars contain the same sort of s-process elements now prominent in FG Sge's spectrum. Perhaps this star is transforming itself from a blue giant into one of these rare types of giant stars. If so, FG Sge should

continue to redden and cool still more; as it does so, the appearance of additional spectral lines should foretell the route it will take.

A difficulty with this model, however, is that some of its features may be unrealistic. But if it *is* correct, then FG Sagittae's planetary nebula is not a typical planetary nebula: most of these nebulae come from stars of approximately solar mass, and most, presumably, do not have central stars that are about to turn into S-type or barium stars. Yet FG Sge's planetary nebula looks perfectly normal — its size, expansion rate, and spectrum display the standard features of all planetary nebulae.

In fact, the only peculiar thing about the nebula is its central star: FG Sagittae is much cooler than the nucleus of any other planetary nebula. Although the extreme heat of the central star causes a planetary nebula to fluoresce, FG Sagittae, now a yellow G-type star, is far too cool to induce fluorescence. Despite this, the nebula has shown no apparent change. Even in 1955, when its spectral type was B4, FG Sge was almost too cool to be responsible for exciting the nebular gas. Presumably, however, the star was much hotter before 1955 and may easily have been an O-type star in 1900. Calculations show that it will take many years for the nebula's appearance to change significantly in response to the rapid cooling of the central star. In fact, one hundred years ago, FG Sagittae may have been a normal central star.

So, then, what is going on? Many astronomers believe the central stars of planetary nebulae continue to burn helium in a shell. Since helium shell burning is unstable, the star could undergo a helium shell flash. Such an event, calculations show, will cause the star to cool and then heat up, returning it to the realm of normal planetary nebula nuclei. In addition, the star's bolometric magnitude would remain about the same throughout the whole process — it traverses a flat loop in the H-R diagram.

The evolution of such an event does not really depend on the star's mass, but on the mass of its degenerate carbon-oxygen core. For a star whose core mass is 70 percent that of the Sun, the time between helium shell flashes is roughly 10,000 years; for a star with a core mass 80 percent that of the Sun, the interflash period is about 4,000 years. A planetary nebula central star with a solar-mass core has an interflash period of about 500 years. The mass of the core also determines how long the star takes to complete its flat loop and return to its previous spot on the H-R diagram. A core with 60 percent of a solar mass takes several thousand years; for a core weighing in at 80 percent of a solar mass, the trip takes on the order of 100 years; and a 1.2 solar-mass core needs only ten years to regain the surface temperature of normal planetary nebula central stars.

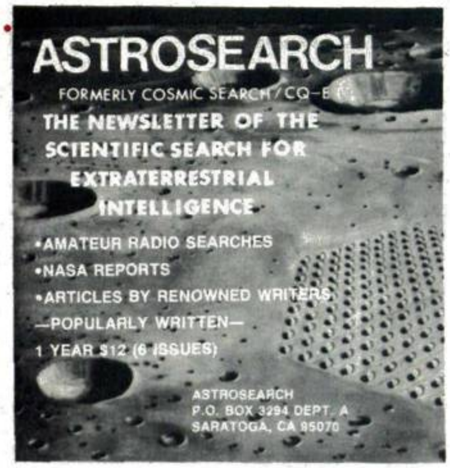
Suppose, therefore, that a helium shell flash ejected a planetary nebula from FG Sagittae when it was a giant, about 6,000 years ago. The star became hotter, residing among the other nuclei of the planetary nebulae on the H-R diagram. Then, shortly before 1894, FG Sge underwent another helium shell flash — one that initiated the cooling trend in the star's surface temperature. Its surface temperature should eventually stop decreasing and begin increasing if this view is correct. This last helium shell flash kicked to the surface the s-process elements created deep in the star. The time lag between the last helium shell flash, which occurred before 1894, and the enrichment of s-process elements on the surface in 1965 is at least 70 years. Recent calculations by California Institute of Technology astronomer I. Juliana Sackmann show that such a time delay is reasonable.

Since the interflash period is about 6,000 years, the core of FG Sagittae should be 70 to 80 percent the mass of the Sun. The core mass, in turn, determines the star's luminosity — in FG Sge's case, a bolometric absolute magnitude of −5.5. This implies a distance of about 13,000 light years, considerably greater than the rather uncertain original estimate. The greater distance also implies that the nebula is at least 9,600 years old. Based on the estimated mass of its core, it should take on the order of 100 years for the surface temperature of FG Sge to return to that of a normal planetary nebula central star.

If this model is correct, we should probably regard FG Sagittae as our first observation of a phenomenon experienced by the central stars of many planetary nebulae. About 120 planetary nebulae inhabit the space within 10,000 light-years of the Sun; their mean lifetime is about 20,000 years. If every planetary went through an FG Sagittae episode once and took about 500 years to complete it, then we should see about three such objects today. Of course, we see only one, but that number still lies in the right range. The suggestion is consistent with observations.

Astronomers will keep a close watch on FG Sagittae's spectrum for possible new elements, as well as for any increase in surface temperature. If, according to the latest suggestion, FG Sagittae returns to its former spot on the H-R diagram, it should gradually cool and fade into a white dwarf. At this star's great distance, a white dwarf would be invisible to even the largest telescopes. Still, long before it fades from view, FG Sagittae will have played a vital role in helping us piece together the puzzle of stellar evolution.

Ken Croswell is a graduate student in astronomy at Harvard University. His last ASTRONOMY article was "Contact Binaries: Stars that Touch," in the December 1982 issue.



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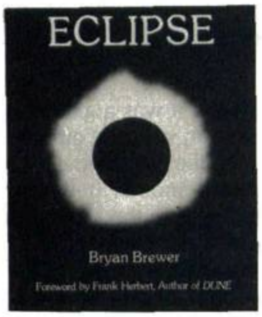

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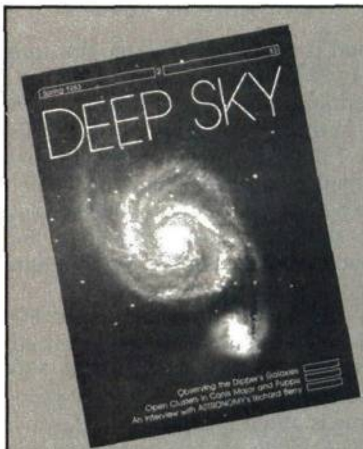
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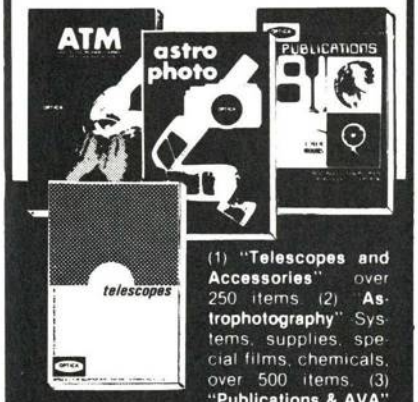

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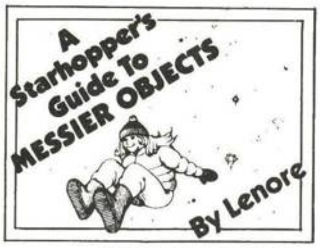

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1983 buyer's guide to astronomical telescopes

Buying a telescope is a big step. Not only will it cost a substantial amount of money, but there's a commitment involved. It's a bit like buying a pair of cross-country skis. And somewhere in the back of your mind, there's that lingering doubt that you're even *worthy* of a telescope.

Still, there's no getting around it. The time has arrived. Having studied the sky, learning constellations and the names of the bright stars, you've thrilled to the Moon, the planets, the Pleiades, the Andromeda Galaxy through binoculars or a friend's telescope.

But awesome questions loom before you: What kind of telescope? Will *any* telescope do? What *features* should I look for? How much should I *spend* on it? What can I *see* with? *Where* should I buy it?

The answer to these questions is that there are no hard and fast answers. The answers really depend on you and your needs.

Physical Size. For a moment, forget that it's a telescope you want. Think of it as a mysterious lump that you must carry around. Now, do you want a small, portable lump, or a larger, more cumbersome lump? Would you use this lump in your backyard or out in the country somewhere? Should it be a long or short lump? A fat or skinny lump? Will it fit in your car? How about complexity — would you prefer a simple lump or a gadget-laden lump? Which kind of lump matches your way of doing things — a "do-it-yourself" or a "turn the key and use it" type of lump?

Forget for the moment that big telescopes generally show you more (and also generally confer more "status"). Instead, ask yourself how much you personally value convenience and portability in a telescope. It's probably a better idea to have a small telescope that you will use often rather than a large telescope that you will use seldom, or never. In any case, answering this question truthfully will point you in the right direction, but it will cost you some honest soul-searching to come up with answers.

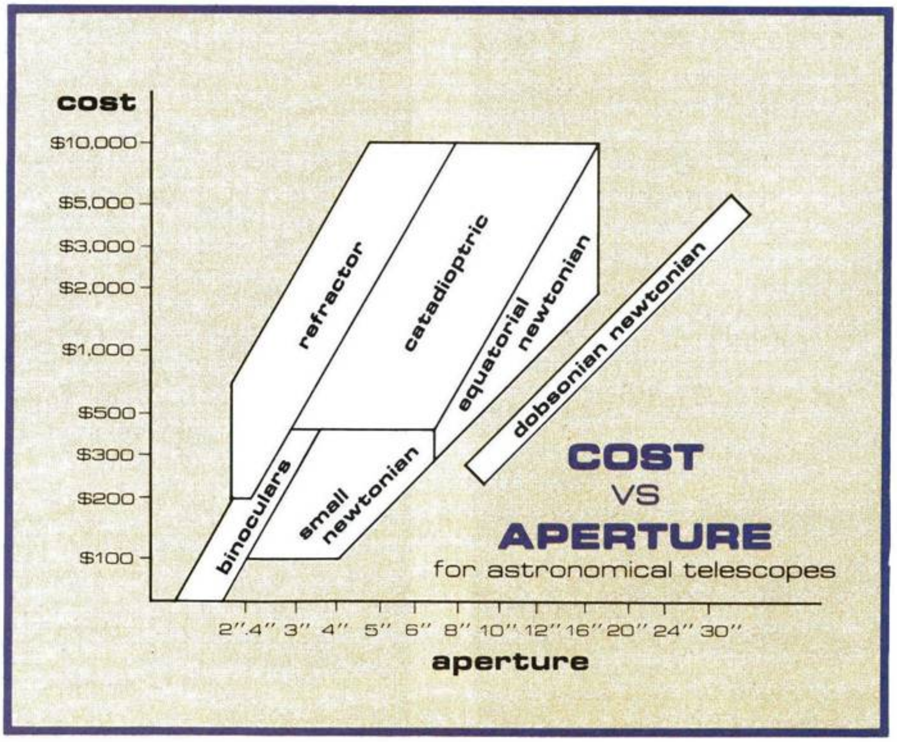
Telescope Aperture. Okay, let's talk telescope types. What one factor counts most in a telescope? Its length? Nope. Its type? Nope. Its cost? Nope. What counts above all else is aperture. Everything hinges on the diameter of the main lens or mirror.

Independent of the type of telescope, the aperture determines the instrument's capabilities: how much light it gathers (and therefore its ability to show you dim objects), the theoretical resolution of the telescope (or how much fine detail it can pick out), and how much magnification you can use.

So, the bigger the better — up to a point. And that point occurs when your desire for aperture conflicts with your desire for convenience.

What can telescopes of different aperture do? Here are some rough guidelines:

- "Small telescopes," under approximately 5 inches of aperture, are best for getting acquainted with the stars. They'll let you survey the whole field of observational astronomy — that thrilling first taste — without paying a penalty in size, weight or cost. Most are portable and easy to use.
- "Medium telescopes," in the 6-inch to 10-inch range, make the best all-around telescopes. They're capable, versatile, yet still reasonably portable. You can observe both planets and galaxies with equal pleasure — from your back yard and distant dark-sky locations — whenever you want.



COST VS APERTURE for astronomical telescopes

- "Big telescopes," in the over 10-inch range, are more capable of doing specific tasks they're designed for, such as deep-sky observing, but are less well suited to a broad range of observing interests. Portability tends to be poor, versatility is reduced, but special capabilities are maximized.

Telescope Types. Most of this article is devoted to the merits and demerits of specific telescope types, so just a few bold pronouncements on this topic now: Aperture for aperture, refractors lead everything else in image quality. But refractor apertures are small. Newtonians offer the most aperture (and therefore performance) *per dollar*. Dobsonian mounts are the least expensive way to mount any telescope, but they're for visual use only. Catadioptric telescopes are compact and portable, but relatively expensive for the aperture. These tradeoffs are not easy — and there is no such thing as an "ideal telescope." Sorry!

Optical Quality. Quality varies from telescope to telescope. The only way you can be sure of buying a telescope of excellent optical quality is to test the instrument you're going to buy before you buy it. That's great for your second telescope. But a first-time telescope buyer has little or no basis for comparison — so you must learn. Go to star parties, look through other people's telescopes, look through *all* the telescopes your local dealer has in stock, and learn to judge good optics. (See "How to Star-Test Your Telescope," in the April 1983 ASTRONOMY for instructions on testing any telescope on any clear night. It's not difficult.)

The alternative is not to worry about optical quality. Buy a small telescope from a reliable firm — and recognize that by the time your eye becomes educated enough to detect its shortcomings (which probably won't be severe anyway), you'll be ready for a bigger, better telescope.

Mechanical Quality. From a user's point of view, mechanical quality usually means "Does the mounting shake?" and "Is the drive accurate?" You can check the first for yourself in about two minutes — aim at a bright star, put in a high power eyepiece, and tap the tube. If it shakes more than you think it should, don't buy the telescope.

The second — drive quality — is quite difficult to test. And as with optical quality, even good drives vary from unit to unit. Look for tight mechanical tolerances and be sure to do plenty of comparison shopping. Quality's going to cost you money, but if you're serious about astrophotography, discovering the drive's deficiencies only when you begin using it for long exposures is sure to be a letdown.

The alternative is not to worry about drive quality. Simply forget about it! If you plan to observe visually, you don't need an accurate drive.

Financial Considerations. Next, let's talk about the bottom line — how much you can afford to shell out. You want to be sure that you spend enough to get a good, solid astronomical instrument, but not more than you have. The best way is to wait until you have enough cash to cover the cost of a telescope that meets your needs. Remember that astronomy is a hobby — you shouldn't have to worry about paying off a telescope loan!

If you're short of money, don't try too hard to find a bargain. There are good reasons why some telescopes are expensive, just as there are good reasons why others are inexpensive. Find yourself a telescope that has a *good* reason for being inexpensive. As for most of those bargain basement, department store ("See 900x!!") telescopes, you might just as well throw your money away.

One option too often forgotten, especially if you're *always* short on cash, is building your own telescope. You can cut the cost for a given aperture telescope by a factor of 2 to 10 and in some cases even more. Chances are that you'll really enjoy building it and learn a lot in the process, too.

Even if money is not a problem, you may want to limit the size of your purchase for other reasons. Don't just go out and buy the biggest telescope you can afford — consider how you carry the thing. And what about storage — do you want to park your car out in the snow so your telescope can be snug and dry?

And while we're talking about money — it has occurred to you that some telescopes have "status symbol" value, hasn't it? If that's what you want, then be honest with yourself, admit it, and buy accordingly. But if you plan to emphasize observing, don't pay a premium price for status.

Traditional Choices in Telescopes

Now that you know the logistical problems of ownership, it's time to get down to some hard trade-offs about the types and sizes available. Traditionally, two instruments were considered "right" for beginners. They were the 2.4-inch f/15 refractor and the 6-inch f/8 Newtonian reflector. Both have significant merits, and in some ways still are good choices.

Refractors. Lightweight and highly portable, small refractors are suitable for anyone who lives in a high-rise apartment. They have a self-contained light path free from convection currents that degrade the

the mounting dilemma: dobsonian or equatorial?

If ever there were a scenario that most (if not all) of us amateur astronomers can relate to, it's this one: After many pleasurable years of ardent observing with your little 2.4-inch refractor (you've *almost* completed that darn Messier catalog!), you finally give in to that nagging urge for a bigger telescope. So you decide to do without a few of life's other pleasures for a while, and spend a few hundred of your hard-earned bucks on a Newtonian reflector in the 8 to 10-inch range.

Sound familiar?

Having made the all-important decisions on aperture size and focal length, you're left with one more major choice to make: the type of mounting. A few years back this choice would have been fairly easy and straightforward: Either you went with the simple alt-azimuth (usually suitable only for tiny imported refractors and a few RFTs), or you opted for the far superior German equatorial mounting, which was billed as the "only" mounting for the serious amateur. It was certainly the only mounting for anyone contemplating astrophotography. Both types had their drawbacks, but the equatorial was almost always the better choice.

Then, in the late seventies, a man named John Dobson entered the scene with some unique mechanical ideas that have radically changed the concept of the portable astronomical telescope. Things haven't been the same since. Dobsonian reflectors have literally taken our hobby by storm, giving rise to the term "Dobsonian Revolution." (I'll never forget when I first heard mention of it — I thought it pertained to some obscure 17th century English war I had somehow missed in my history books!)

A bit of explanation is in order for all you newcomers wondering what the Dobsonian fuss is all about. Why does it open up new possibilities (and require new choices)?

Technically speaking, the Dobsonian mount falls in the "alt-azimuth" category. It moves up and down in altitude and rotates on its base. The big difference is in configuration. Whereas in the standard "old-fashioned" alt-azimuth, the mounting is self-contained and supports the tube assembly, in the Dobsonian concept the tube assembly and the lower base are an integral part of the mounting. In most cases, the bearings for altitude motion are permanently mounted on the tube itself or on a box holding the tube. The box rests in a wooden "cradle box," which in turn rotates on a ground-board, utilizing any of a number of bearing or caster systems. The Dobsonian's center of gravity is always directly over the center of rotation on both axes, no matter where you point it in the heavens. The final result is infinitely more stable than the old alt-azimuth mounting. Properly constructed, it can move smoothly with the touch of a finger, stays where you point it in the sky, and gives rock-steady star images. The perfect mount, right? Well . . .

Obviously, the Dobsonian mounting is not for everyone. As you've probably guessed by now, its major drawback is that it cannot (at least without extensive modification) follow the motion of the stars without your intervention. You are the "clock drive" — you push it to follow the stars.

Here's where you make that important decision: Which type of image. But the price of refractors runs considerably higher than that of reflectors with somewhat larger apertures.

A good 2.4-inch refractor costs between $275 and $500. Many come equipped with an alt-azimuth mounting — one that goes up and down and back and forth, which is not well suited to photography. It would be wise to anticipate the need of an equatorial mounting — one that follows celestial objects with a single motion.

Though equatorial mountings are more expensive, they give greater control over tracking the telescope's highly magnified image. If you have a strong desire to try astrophotography (or anything requiring constant tracking with a clock drive), then the equatorial mounting is best for you. It is expensive and heavy, but well worth its weight for the tracking it provides.

Larger refractors soon move outside the realm of affordable beginner instruments. The step from 3 to 6 inches skyrockets the price from $500 or $1,000 to $3,000 to $8,000. As an additional cost, any refractor much above 5 or 6 inches in aperture should be permanently mounted because its sheer size will make it very difficult to transport. A 4-inch achromatic refractor will probably be at least 5'6" long, and a 6-incher at least 8 feet.

Newtonians. Newtonian reflectors were long the standard amateur instrument; recently the more portable catadioptrics have taken the lead. Whatever their other merits and demerits, however, Newtonians still offer more telescopic performance per dollar than any other type of telescope.

If you want a reflector, a good starting size is a 6-inch. With such an instrument, all the Messier objects will be visible, as well as an impressive amount of detail on the planets. They are easy to build if you want to make your own, easy to use, and the optical design is straightforward and reliable. They contain two glass mirrors — one curved, the other flat — both aluminized to make them reflective.

Newtonians come in focal ratios from f/5 to f/10, with tube lengths ranging from 3 to 6 feet long; with a solid equatorial mount the whole telescope may weigh up to 100 pounds. But when dismantled into their components, these scopes are very manageable — about halfway between portable and transportable. The cost of a good 6-inch f/8 reflector runs from $300 to $600, including shipping and crating.

Today, however, more and more observers are leaning toward medium-size Newtonian reflectors — 8-inch and even 10-inch apertures are common. With a scope this size, you'll see a lot of planetary detail — Jupiter's Red Spot will pop out at you, and the martian polar caps will shine in your eyepiece. The bigger mirror collects more light rays coming in from galaxies and nebulae, and you'll see fine views of these deep-sky objects every night. Scopes this size — with prices running from $500 to $1,600 — are usually supplied with equatorial mounts and clock drives. Their tubes will be from five to eight feet long, and the whole apparatus — mounting and scope — might weigh several hundred pounds.

Large reflectors are tempting because they can reveal some of the striking details visible in observatory instruments. Today, many reflectors from 12 inches to 29 inches in aperture are in the hands of hobbyists. A big instrument requires dark skies — and therefore you must be willing to make the effort to carry it or place it permanently in a dark sky location. It is in this size range — the real biggies — that a Dobsonian-mounted Newtonian really comes into its own. They can be so big that if you tried to mount one equatorially, you couldn't afford the price!

If you're thinking of purchasing such a telescope, consider it carefully since it will require a much greater commitment than a smaller scope. Prices for equatorial Newtonian instruments this size run from $1,400 to $10,000; a Dobsonian of the same aperture costs about half as much.

New Choices in Telescopes

Shortly after World War II, optical designers introduced a series of new optical systems called catadioptrics. These instruments use combinations of mirrors and lenses to produce the image, rather than relying on either type of optics alone. The construction of these mirror-lens systems is tricky, but within the last 20 years, optical companies have found ways to mass-produce them for the consumer market.

Although they generally cost more than reflectors on an aperture-for-aperture basis, they are less expensive than refractors, and they offer a compactness that neither of the classic designs possesses. Their compactness and resulting portability makes them nearly ideal as medium-aperture instruments. Naturally, the cost of this advantage goes up rapidly with the size of the scope, but small-aperture, ultra-portable models cost between $400 and $900.

Maksutovs. The Maksutov is the original catadioptric. It uses two mirrors and a thick, deeply curved lens. This design is extremely compact and rugged — and often finds use in telephoto lenses as well as in telescopes. Typical sizes commercially available range from 3 to 7 inches of aperture with a tube assembly only 1 to 2 feet long. One manufacturer even offers a 12-inch Maksutov, but at a

mount would be best suited for *your* kind of observing? Generally speaking, an equatorial mounting is almost an essential if you do a lot of lunar, planetary, or double star observing at high magnification. Or if you rely on setting circles to locate sky objects. Or if astrophotography figures in your future in a big way. However, if you're a "star-hopping" deep-sky enthusiast, use a low to medium-power ocular most of the time, and don't spend a great deal of time viewing any one object, then a Dobsonian could be the biggest boon to your observing pleasure since electric socks. Let's examine a few of the other advantages this mounting has to offer:

When it comes to transporting telescopes to out-of-town observing sites, weight of the instrument becomes a BIG consideration. An 8 or 10-inch reflector with a sturdy steel and chrome equatorial plus pedestal may weigh considerably more than you do. The equivalent Dobsonian will weigh only a fraction as much. This is due not only to the light-weight materials used in construction, but also to the fact that the Dobsonian requires no counter-balance weights. To lighten equatorials, many telescope manufacturers are now producing them out of aluminum and other alloys. Of course, the German equatorial still requires counterweights, which, regardless of the materials they're made of, account for much of the total weight.

If your quality observing hours are precious, the time you spend setting up a telescope can be important. This is especially true if you make many field trips. Most equatorially mounted scopes must be broken down into three or four pieces before they can be loaded into an average-sized car. Re-assembling those pieces at the site with wing nuts, washers, and bolts can be a real pain — especially in the dark. After this is finally accomplished, the polar axis must then be lined up with Polaris, consuming still more time. The Dobsonian, in contrast, almost always breaks down into two very manageable pieces: the tube/bearing assembly and the cradle-box/base assembly. Set-up is as easy as lowering the former into the latter: no hardware to lose and, more important, no lost observing time.

Due to its inherent low design, in most cases the Dobsonian mount allows the observer the comfort of viewing while seated. This may seem like nit-picking, but if you've ever spent a lengthy evening wrenching your neck with a German equatorial (especially one without a rotating tube), then you'll appreciate the pleasure of non-contorted observing.

Another big advantage of the Dobsonian mounting, which almost goes without saying, is the ease with which one can be homebuilt. While constructing a quality German equatorial requires a metal lathe and other precision tools, you can assemble a simple Dobsonian using basic household tools you probably already have in your garage. It's inexpensive, and what's more, it can be a lot of fun.

Even if you now own an equatorially mounted telescope, you might consider building a Dobsonian for increased portability and enjoy the best of both worlds. (See "How to Make Your Newtonian Telescope Somewhat More Portable," ASTRONOMY, May 1983.) You may just find yourself throwing your scope in the car and heading for those rural skies a lot more often.

Dobsonian scopes are built using plywood and rolled paperboard tubes. The only real expense in the mounting is the bearings, which are usually Teflon plastic. When you add to that the new inexpensive thin objective mirrors, what you end up with is an economical (but by no means inferior) large-aperture reflector. Who would have very high price.

The image produced by a "Mak" is clean and crisp and, of all the types of telescopes made, most closely resembles the images produced by a refractor. Its closed tube and extremely small size make it ideal for a city-bound stargazer who wants to see crisp planetary images and clearly separated double stars. Dollar for dollar, however, Maksutovs are more expensive than other types, and their small apertures mean they don't gather much light. Although exquisitely crafted, the $500 to $3,000 price tag often places them beyond the reach of most beginners.

Schmidt-Cassegrains. Schmidt-Cassegrain telescopes, or SCTs, are catadioptrics that employ a thin corrector lens at the top of the tube to transmit light back to a large mirror, which in turn reflects it back to a secondary mirror located in the center of the corrector lens. This small mirror then reflects the light back to focus, into the eyepiece and ultimately to the eye of the observer.

The tube of an 8-inch Schmidt-Cassegrain is about 2 feet long and weighs around 10 pounds. These telescopes are usually supplied with a fork mounting that the tube swings through. For compactness, they can't be beat. Such a compact mounting is almost ideal for taking on observing trips and to star parties. They are easy to transport and quick to set up; they are a familiar sight at every telescope gathering. One person can manage a 14-inch Schmidt-Cassegrain, though not without some difficulty. When broken down into its component parts, a telescope of this type can be transported in a small car — a virtual impossibility with a same-aperture Newtonian.

Prices run from $600 to $1,200 for instruments with objective diameters of 5 to 8 inches; complete larger Schmidt-Cassegrains between 10 and 14 inches in aperture cost $2,000 to $6,000.

RFTs. They've been around for decades, but they're still growing in popularity. "Rich-field" telescopes combine the advantages of large binoculars with the resolving power of a telescope. What are they? Simply Newtonian reflectors with short focal lengths — usually between four and five times the aperture. Most big Dobsonian telescopes are, in fact, just overgrown RFTs. The advantage of an RFT design is that it takes a large-aperture telescope and scales it down to a more manageable size.

A typical 6-inch aperture RFT is only two feet long; it can be handheld, placed on a little Dobsonian mount, or mounted equatorially for prime-focus photography. Many people use an RFT to supplement the restricted field of view of their primary instrument, often mounting it "piggyback" on another scope.

RFTs are excellent for general scanning or viewing star clusters and other large and faint objects. From a dark-sky site, the view through an RFT is breathtaking — you get a very bright image in a wide field of view. The relatively short focal length means that it can produce low magnifications with normal eyepieces. For observing nebulae, galaxies and other extended objects, RFTs are tops. And those with large-aperture mirrors collect a great amount of light, so sky objects that go unseen in small scopes seem to pop right out.

Schmidt-Newtonians. The "new kid on the block" this year is the Schmidt-Newtonian. Optically, it's a Newtonian reflector with a spherical primary mirror and a thin correcting plate to remove aberrations. From the user's point of view, it's an RFT — low focal ratio, short tube — best for deep-sky and other types of low-magnification observing. A Schmidt-Newtonian costs considerably more than than the equivalent Newtonian, but gives somewhat better optical performance at the margin of a wide field, especially for deep-sky astrophotography.

Weighing Time, Money, and Patience

Buying a telescope is a major step in pursuing your astronomical hobby — the cash outlay alone makes careful consideration a must. The best way to stimulate interest in and increase the enjoyment of your hobby is to get a telescope that will be easy to use, capable of resolving the objects you want to see, but won't put a strain on the time you can give to observing. If it takes you 45 minutes just to set up your telescope, then that's 45 minutes less you have for the stars. For that first telescope, think small and simple.

Your prospective new telescope should encourage and supplement your present viewing habits, not overwhelm you. "Jumping in over your head" is a mistake that's far too easy to make — especially considering the encouragement you'll hear from those who want you to buy their product. It's possible you'll find out you don't want to commit your time to staying outside late at night and freezing your toes off. Think twice about yourself and your enjoyment of astronomy. If binoculars or casual observing with your eyes alone satisfies your observing needs, then you can continue happily without any further expense. But if you feel a telescope will open more windows on the universe for you and help you derive greater pleasure from your hobby, then by all means determine the scope that's best for you and head for clear skies.

thought a decade ago that it would be possible to own a telescope in the over 20-inch class for thousands of dollars less than the average economy car? No wonder that these "new kids in town" have created such a stir! Celestial views that were once only a dream are now within reach of the average budget.

By now, most of you who read this must believe I have been paid off by some big company to write this article. Surprise! The mounting that supports my beloved 8-inch reflector is a German equatorial. And even though I'm one of those deep-sky "star hoppers" for which the Dobsonian was intended, I don't believe I'll forsake my cast-iron, weatherbeaten monster. Call me sentimental, or perhaps stupid, but I'm one of those die-hards who don't mind carting around the extra weight, the extra set-up and polar alignment time, and yes — even the neck wrenching. I feel I really have to *earn* my deep-sky objects. But mostly I like the ease of equatorial tracking when I occasionally put in that high-power eyepiece.

Despite the pros and cons of each mounting type, one thing now seems certain: Dobsonians and equatorials are both here to stay. Each is destined to play an important role in the future of amateur astronomy. And in the long run, both help us accomplish the same thing: enjoyment of our visible universe.

— Gary W. Keltner

mail-order telescope buying

When buying by mail, there's no substitute for knowledge. And it's *you* who must learn enough about telescopes to buy intelligently. Begin by doing your homework. Join an astronomy club. Talk to other people who have ordered similar equipment. Ask them how they were treated, whether they received prompt delivery, and if you can, arrange to examine and use the make and model telescope you're considering. Research your prospective instrument; don't let clever advertising copy and your own wishful thinking sell you something you know nothing about.

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the backyard astronomer

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Mercury

On October 1st, Mercury will reach greatest western elongation from the Sun. Forty-five minutes before sunrise on that date, it will have an elevation of about 9° in the east. Mercury will remain visible until about the third week of the month; superior conjunction with the Sun comes on the 30th. This is the year's best apparition for the little planet, so make the most of it.

If you follow Mercury with a telescope, you'll see its phase round out from half-lit and 7.1'' of arc across on the 1st to 98% lit and 4.9'' across on the 21st.

Venus

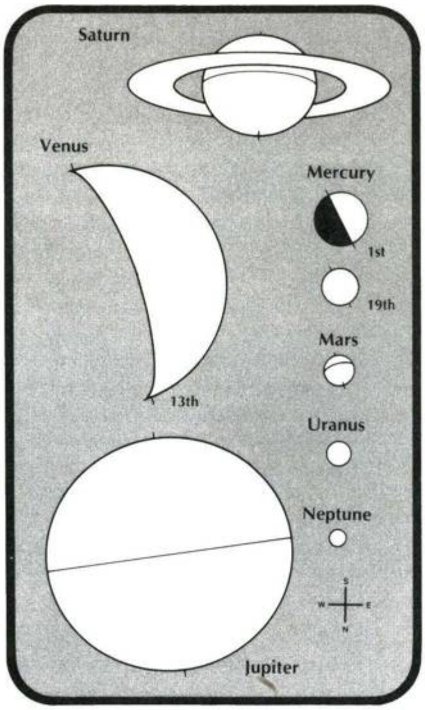
During October, Venus will climb to nearly its maximum elevation in the eastern sky. (Greatest western elongation comes on November 4th, a day or two past highest elevation.) Greatest brilliancy occurs on the same date as Mercury's greatest elongation — October 1st. This is the time when the planet will appear at its brightest, −4.27 magnitude.

On the 28th, Venus will pass 1.7° south of Mars — close enough so that your lowest telescopic powers ought to fit them both in the same field of view. Venus will be 46% lit and 27'' of arc across. Mars, which is intrinsically smaller than Venus and over three times farther away, will appear 4.3'' of arc across and will look round.

Mars

At the beginning of October Mars is rising 4 hours before the Sun; this becomes 5 hours by the end of the month. Mars is moving steadily southeastward along the ecliptic through the constellation Leo.

The close match between the orbital speeds of Earth and Mars (30 km/sec to 24 km/sec) produces long apparitions of this planet. Compared to the more slow-moving outer planets like Jupiter and Saturn, we have seen Mars take a long time to be caught by the Sun in the evening sky — and it will now gain altitude in the morning sky very slowly as well.



As a result, its apparent diameter enlarges with what may seem to an impatient observer to be a glacial pace. The minimum size for adequate viewing of martian surface features is when the planet has a diameter of at least 6'' of arc — a size it won't reach until January. In the meantime, you should "check in" on Mars regularly to keep your eye in practice.

Asteroids

1 Ceres (magnitude 8.1) lies near the corner where Capricornus, Piscis Austrinus, and Microscopium meet. Its positions:

10th: 21h 22m 54s, −28° 33.1'
20th: 21h 24m 43s, −27° 52.4'

Ceres rises around 7:30 p.m. local daylight time on the 15th.

2 Pallas (10.2) will slice southeastward through the northeast corner of Serpens Cauda during October. Its positions:

10th: 18h 38m 04s, +6° 33.7'
20th: 18h 45m 56s, +5° 04.6'

Pallas sets about midnight local daylight time at mid-month.

3 Juno (7.5) is at opposition in Cetus on October 24th. On the 19th and 20th it will pass about 12' of arc west of the famous long-period variable star, Mira (Omicron [o] Ceti). Its positions:

10th: 2h 24m 02s, −0° 40.8'
20th: 2h 18m 39s, −2° 52.9'

Juno is visible all night long.

4 Vesta (7.6) lies on the border of Orion and Taurus, near the Hunter's upraised club. Its positions:

10th: 5h 52m 14s, +18° 00.5'
20th: 5h 55m 14s, +17° 58.8'

Vesta rises around 11 p.m. local daylight time on the 15th.

To facilitate plotting their positions on a star atlas, all asteroid coordinates are for the epoch 2000.0.

Jupiter

It is clear that Jupiter will not remain visible in the evening sky much longer. It is sinking ever lower each night and will disappear into the oncoming twilight during November. Get in what observing you can now, but don't expect to see the planet's belts and storm systems very clearly — you are looking through a steadily thickening layer of atmosphere whose distortions will prevent crisp views.

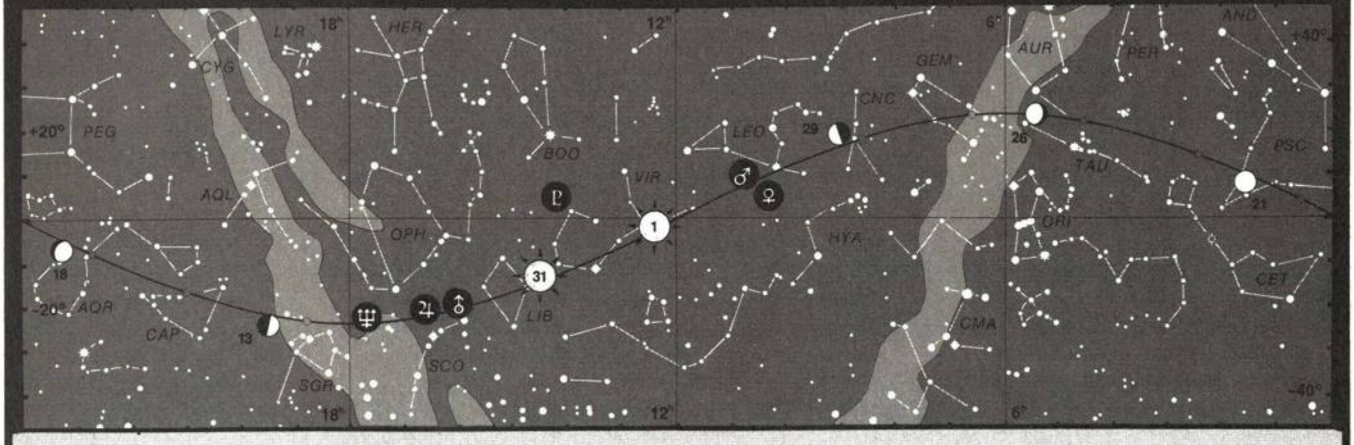
Saturn

Saturn is too close to the Sun to be

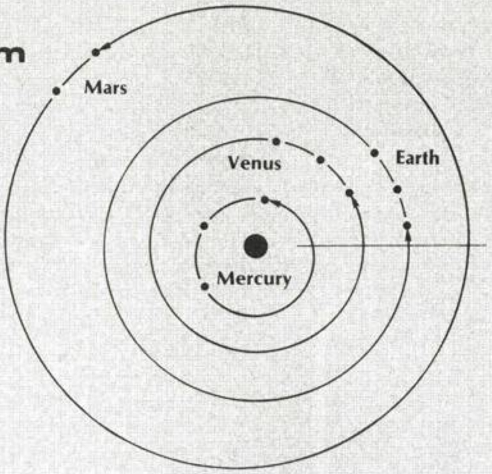
Jim Baumgardt's Hα photograph of a solar prominence, taken on June 25th, wins this month's "Best Astro-Photo" award. He used a 12½-inch reflector stopped to 3½ inches, eyepiece projection, and a 1/125-second exposure at f/70 on hypered 2415 film. A little darkroom work then produced an artifical eclipse.

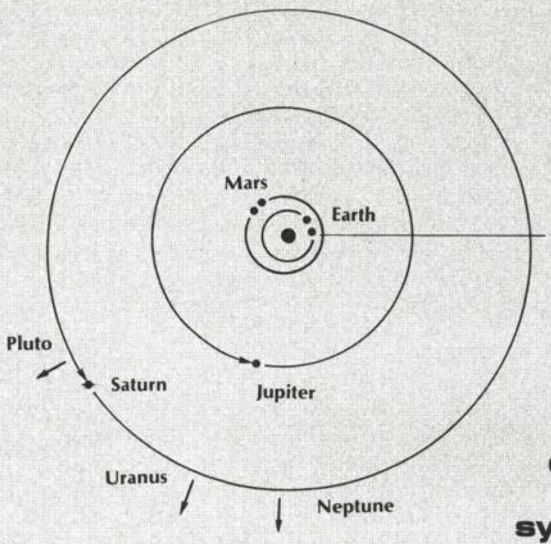
For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

planetary data october 1983


LYR
18h
HER
12h
6h
AUR
AND
+40°
CYG
GEM
PER
CNC
+20°
PEG
LEO
29
26
BOO
VIR
PSC
TAU
AQL
21
ORI
HYA
1
OPH
18
31
CET
-20°
AQR
LIB
CAP
13
CMA
SCO
SGR
18h
12h
6h
-40°

inner solar system


Mars
Venus
Earth
Mercury


Mars
Earth
Pluto
Saturn
Jupiter
Uranus
Neptune

outer solar system

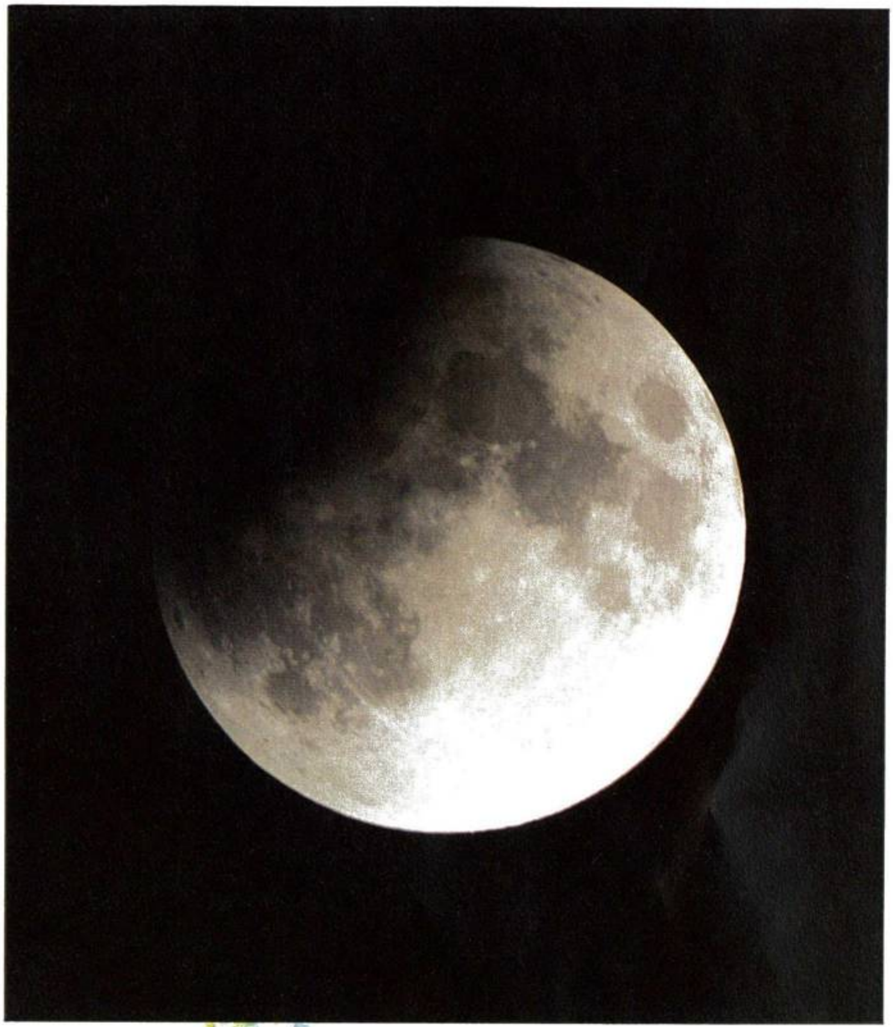
		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (1983.8)	Dec.
Sun		1	−26.7	32.0′	—	1.00	—	—	187°15.3′	12h 26.6m	− 2°52.5′
		15	−26.7	32.1′	—	1.00	—	—	201°04.5′	13h 17.8m	− 8°13.2′
		31	−26.8	32.3′	—	0.99	—	—	216°59.9′	14h 18.6m	−13°50.9′
Mercury	☿	1	−0.2	7.1″	49%	0.95	0.31	78°01.6′	169°19.7′	11h 22.8m	+ 5°14.6′
		15	−1.0	5.2″	92%	1.28	0.36	157°47.0′	189°37.2′	12h 39.9m	− 2°17.3′
		31	−1.0	4.7″	100%	1.43	0.44	217°40.5′	216°42.4′	14h 19.9m	−13°32.4′
Venus	♀	10	−4.2	33.7″	34%	0.50	0.72	44°23.6′	152°28.9′	10h 15.0m	+ 8°03.0′
		31	−4.1	25.7″	48%	0.65	0.72	78°08.7′	170°08.3′	11h 25.4m	+ 3°51.0′
Mars	♂	15	+1.9	4.1″	96%	2.26	1.66	135°35.1′	158°47.8′	10h 45.4m	+ 9°21.1′
Jupiter	♃	15	−1.4	33.2″	100%	5.93	5.31	257°07.8′	248°38.7′	16h 29.9m	−21°21.6′
Saturn	♄	15	+0.8	15.5″	100%	10.78	9.81	216°44.0′	214°49.9′	14h 15.0m	−11°12.5′
Uranus	⛢	15	+6.0	3.5″	100%	19.66	18.97	248°47.3′	246°16.7′	16h 19.2m	−21°21.6′
Neptune	♆	15	+7.8	2.4″	100%	30.66	30.26	268°33.5′	266°27.7′	17h 46.3m	−22°12.6′
Pluto	♇	15	+13.9	0.1″	100%	30.80	29.86	209°25.1′	208°40.9′	14h 11.3m	+ 4°11.4′

moon data

New Moon	October 6 at 11:16
First Quarter.........	October 13 at 19:42
Full Moon...........	October 21 at 21:53
Last Quarter..........	October 29 at 3:37
New Moon........	November 4 at 22:21
First Quarter........	November 12 at 15:49
Perigee: Oct. 4 at 11:16.....	362,429 km.
Apogee: Oct. 16 at 7:53.....	404,814 km.

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times given in The Backyard Astronomer are UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5: MDT, 6; PDT, 7; Alaska, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then EDT for the event is 11 p.m., June 6. Likewise, 03:00 UT on September 2 becomes, in PDT, 8 p.m., September 1.



The partial lunar eclipse on June 25th — half a lunation after the big solar eclipse over Indonesia — was the subject of Ivan Dryer's photo, taken with a 4-inch refractor at f/15 (prime focus) on 64 ASA film. The time was 7:35 UT; the crater Plato has just been engulfed by the Earth's umbra.

observed this month. It passes through superior conjunction on the 31st and will then reappear in the morning sky late in November.

Uranus

Uranus was passed by Jupiter on September 24th; the easiest way to locate it is to offset from the brighter planet. Insert a low-power eyepiece, center your scope on Jupiter, and then sweep westward some 10 to 15 minutes of right ascension. Uranus' disk is 3.5" of arc in diameter and at sixth magnitude. Unfortunately, the observational problems that afflict Jupiter are just as bad with Uranus. The planet is now well past its prime and won't be seen easily until next spring.

Neptune

Neptune is another object that's becoming increasingly hard to see. Located about a degree north and about 15 minutes of R.A. west of M-20, the Trifid Nebula, Neptune is an eighth-magnitude dot of light 2.4" of arc across.

Meteors

October's two showers — the Draconid on the 10th and the Orionid on the 21st — are not very plentiful. The peak time of the Draconids comes during daylight for North America, and the maximum number of meteors visible the nights before and after is likely to be about 10 to 20 per hour. The Moon, at least, will set early. The Orionids are somewhat more plentiful — about 25 per hour — but on the date of maximum activity the Moon is Full and will be spilling its light across the sky all night long.

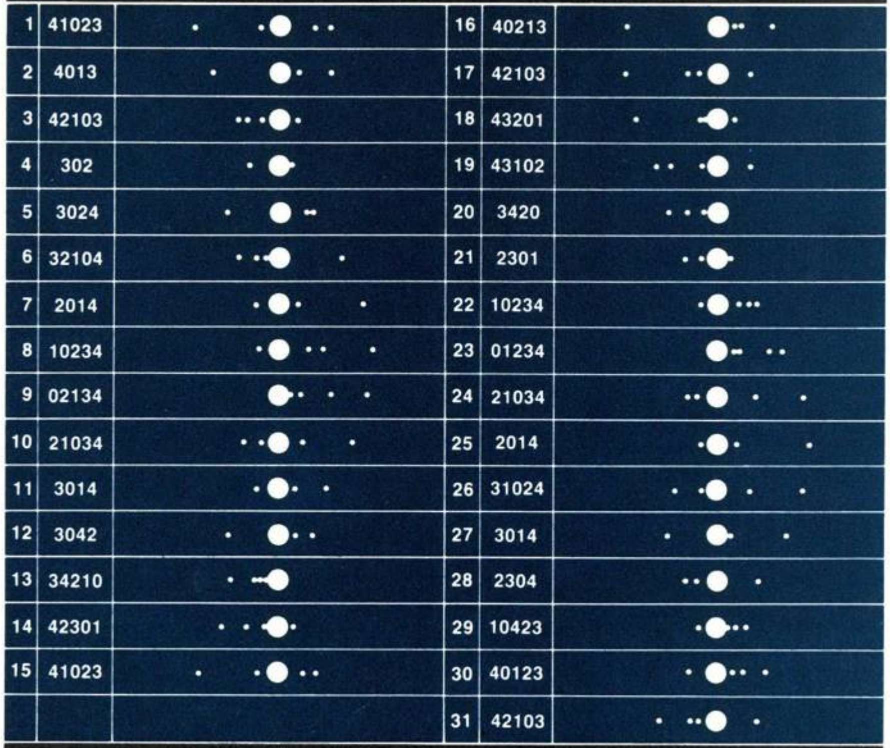
The Draconid radiant lies near the head of the Dragon; that for the Orionids is near the Hunter's club.

close-up on cepheus

Although **Cepheus** the King isn't a bright or spectacular constellation, it lies on the fringes of the northern Milky Way, sandwiched between Cassiopeia, Cygnus, and Draco, and offers a plentiful selection of deep-sky objects. Be sure to take advantage of the cool, crisp nights of autumn — in many places the steadiest nights of the year — as you sweep this area with your telescope. Use a wide-field eyepiece at first, and change to your high-powered ocular only after spotting your target.

The most unusual object in Cepheus is **IC 1396**, a huge faint complex of emission nebulosity that has a notoriously low surface brightness. In spite of the fact that

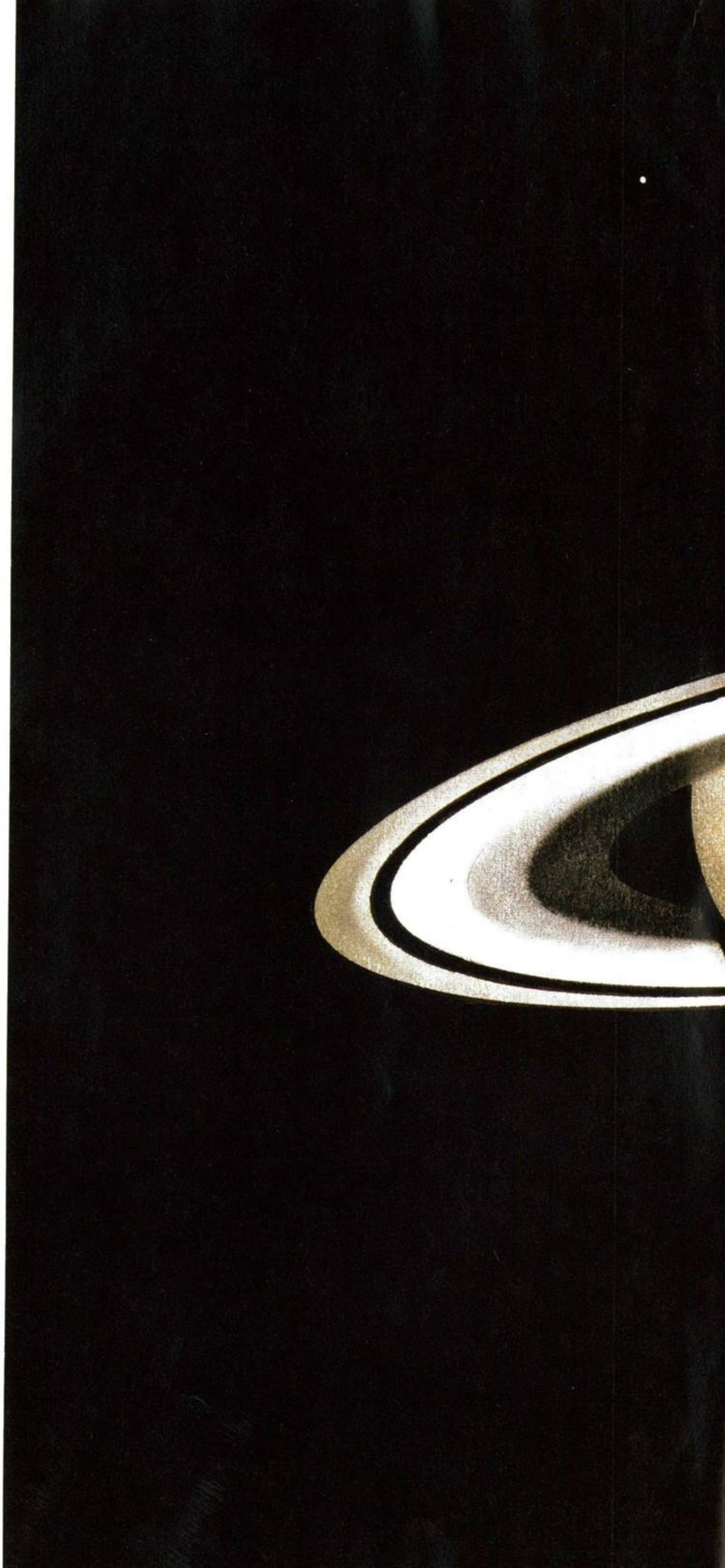
satellites of jupiter 0:00 UT



1	41023	16	40213
2	4013	17	42103
3	42103	18	43201
4	302	19	43102
5	3024	20	3420
6	32104	21	2301
7	2014	22	10234
8	10234	23	01234
9	02134	24	21034
10	21034	25	2014
11	3014	26	31024
12	3042	27	3014
13	34210	28	2304
14	42301	29	10423
15	41023	30	40123
		31	42103

Jupiter = 0, Io = 1, Europa = Ganymede =3, Callisto =4
(South is at top, matching the view in a telescope)

Mark Daniels made this drawing, which shows Saturn and two of its moons at 9:00 UT on March 28th. The planet's ring-system was tilted about 16° to our line of sight. To observe, Daniels used an 8-inch Newtonian reflector and eyepieces that gave powers of 282x to 381x. He rated the seeing as "good."



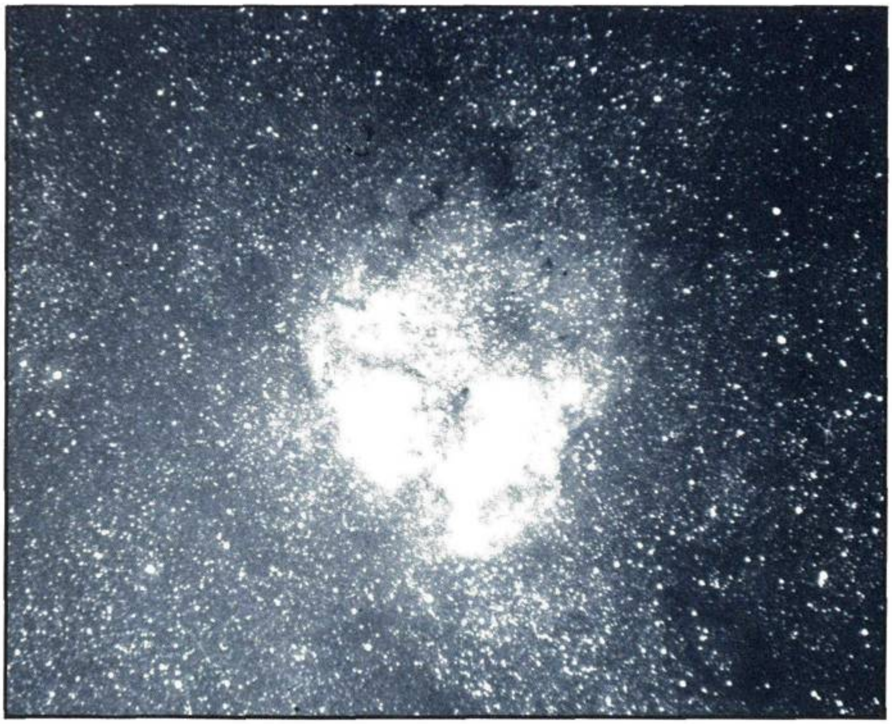
E.E. Barnard discovered this object visually using a 6-inch lens, it is tough to see. You may pick up a misty patch of nebulosity spanning 6 square degrees if you use a 6 or 8-inch RFT at low power, but only from a very dark-sky site. The nebula's central star — the sun that excites the gas into shining — is unknown, but the interesting variable star **Mu (μ) Cephei** lies on the nebula's northern tip. William Herschel named Mu Cep the "Garnet Star" because of its deep ruddy color; it is, in fact, one of the reddest stars known and the reddest star visible to the naked eye in the Northern Hemisphere. Classed as spectral type M2 Ia, the Garnet Star is a red giant much like Betelgeuse; it pulsates, but is always at least several hundred times the size of the Sun.

Over a period of some 755 days, the Garnet Star varies between magnitudes 3.7 and 5.0, and — so many observers say — changes color in the process. Although it normally appears deep orange-red, it occasionally becomes "purplish." Compare it to nearby Alpha (α) Cephei (a brilliant white star) and see what you think.

The other large emission nebula in the constellation is **NGC-7822**, a broad, looping arc covering about 12 square degrees of sky and, like IC 1396, exceedingly faint. Unless you've got a large RFT or binoculars and excellent seeing conditions, you probably won't be able to detect this nebulosity. If you do, the brightest part may show itself as a subtle brightening against the slightly darker sky background. This is a difficult deep-sky object to find. However, on the nebula's northwestern edge is the fine open cluster **NGC-7762**, a 10′ diameter group of seventy 12th to 15th magnitude stars. NGC-7762 is easy to find — it glows at 10th magnitude — and is a nice object at high magnifications.

Other open clusters abound in Cepheus. **NGC-7510** is a small but bright grouping, an aggregate of 100 suns glowing at 10th magnitude and fainter. With a 4-inch telescope at low power, you'll be able to see 30 stars, most brighter than 12th magnitude, packed into a 3′ diameter. Astronomers believe that 7510 is the centerpiece of the Cassiopeia II association — a loose grouping of young O and B stars that were perhaps born together. The faint companion cluster **King 19** and **Markarian 50** (31′ east and 20′ west, respectively) probably have no physical connection with NGC-7510.

NGC-188 is not a particularly bright or impressive open cluster, but is much renowned as the oldest such object



William Herschel's "Garnet Star" — Mu (μ) Cephei — and its neighbor, the diffuse nebula IC 1396, were photographed by Jack Marling. He used a 200 mm telephoto lens, hypered 2415 film, an Hα filter, and a 60-minute exposure at f/2.8. (Mu and IC 1396 are discussed in this month's "Close-up" section.)

known — it formed between 12 and 16 billion years ago, making it older than some globular clusters. It lies just a degree south of the fourth-magnitude star 2 Ursae Minoris; with low-power oculars, the cluster appears as a large (34′) hazy mottled patch. Its 2,200 constituent stars range from 10th to 18th magnitude, but with an 8-inch scope you'll probably see 100 stars and some haze spread over a 15′ diameter.

Another interesting open cluster is **NGC-6939**, a group nearly as rich as NGC-188. This array of suns contains 100 stars between 12th and 16th magnitude in only an 8′ diameter. If you observe with at least a 6-inch scope, use low power and sweep around the group. You'll see a small nebulous bunch of tiny stars and a bonus — the galaxy **NGC-6946** some 38′ to the southeast. NGC-6946 is one of the nearest spiral galaxies — it is an Sc-type object turned face-on — and may be a member of our Local Group. It lies between 10 and 20 million light-years away and is receding at a rate of 200 miles per second. This galaxy has shown a high rate of supernovae: exploding stars have appeared in 1917, 1939, 1948, and 1968. Keep your eyes peeled — maybe one day you'll detect another!

An 11th magnitude object, NGC-6946 is spread over an 8′ diameter, which makes its surface brightness low. The stellar nucleus and some nebulous haze are easily visible in a 3-inch scope, but you'll need a 6-incher to see any outer detail. A 16-inch telescope at moderate power shows this galaxy's delicate, counterclockwise spiral arms, which wrap around knotty bright and dark patches of gas and dust.

Cepheus contains a handful of planetary nebulae; the two most interesting are **NGC-40** and **IC 1470**. NGC-40 measures 40″x60″ and shines at magnitude 10.5, making it visible in virtually any telescope — provided you use high enough power to distinguish it from a star. Its 11th magnitude central star is conspicuous even in a 3-inch instrument. The annular disk appears pale greenish-white and is a nice sight in an 8-inch scope at high power. IC 1470 is larger than NGC-40 — 45″x70″ — but is also much dimmer and therefore has a low surface brightness. Use a medium-power eyepiece (100x to 150x) to find a 12th magnitude white star with a ring of fuzziness encircling it — that will be IC 1470. It's nothing spectacular, but still it's a nice sight.

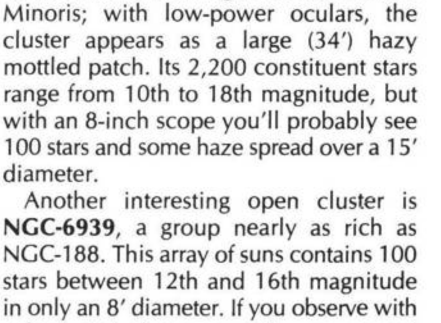
Identified as variable by John Goodricke in 1784, **Delta (δ) Cephei** is the prototype of the most useful and famed class of variable stars, the Cepheids. This type of variable does not undergo an eclipse that blocks out light; rather, Cepheids physically pulsate due to the heating of ionized gases deep within them. There are some 500 Cepheids known in the Milky Way; all are luminous white and yellow giants (spectral types F, G, and K). Delta Cephei itself is an F5 star at maximum (magnitude 3.6) and changes to a type G3 star at minimum (magnitude 4.3). The rise to maximum takes about 1.5 days, and the fall downward about another 4; the total period is 5.37 days.

To observe the changes in brightness of this famous star, compare its brightness with nearby Epsilon (ε) Cephei and Zeta (ζ) Cephei. Epsilon is a 4.2 magnitude star, and Zeta shines at magnitude 3.4. Thus when Delta is at maximum it will nearly equal Zeta; when it is at minimum it will shine with almost exactly the same intensity as Epsilon. (See "Estimating Magnitudes," ASTRONOMY, March 1980.)

The Cepheids are historically and astrophysically important as indicators of distance. Astronomers found that the absolute magnitude of a Cepheid was directly related to its period of variation. If a Cepheid's period is determined, we can deduce how far away it is from its apparent magnitude, since we know its absolute magnitude. We can also tell how far away objects that contain Cepheids are. In 1923 Edwin P. Hubble photographed Cepheid variable stars in M-31, the Andromeda Galaxy. At the time, however, no one knew what a galaxy was and thought that the Milky Way contained the entire universe. By identifying Cepheids in M-31 that appeared to be very, very faint, Hubble discovered the nature of galaxies and for the first time, established the scale of the universe.

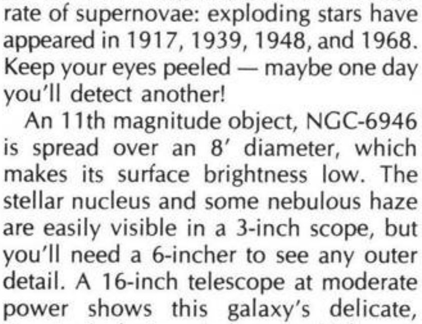
NGC-40

8-inch scope at 100x



NGC-6946

8-inch scope at 35x

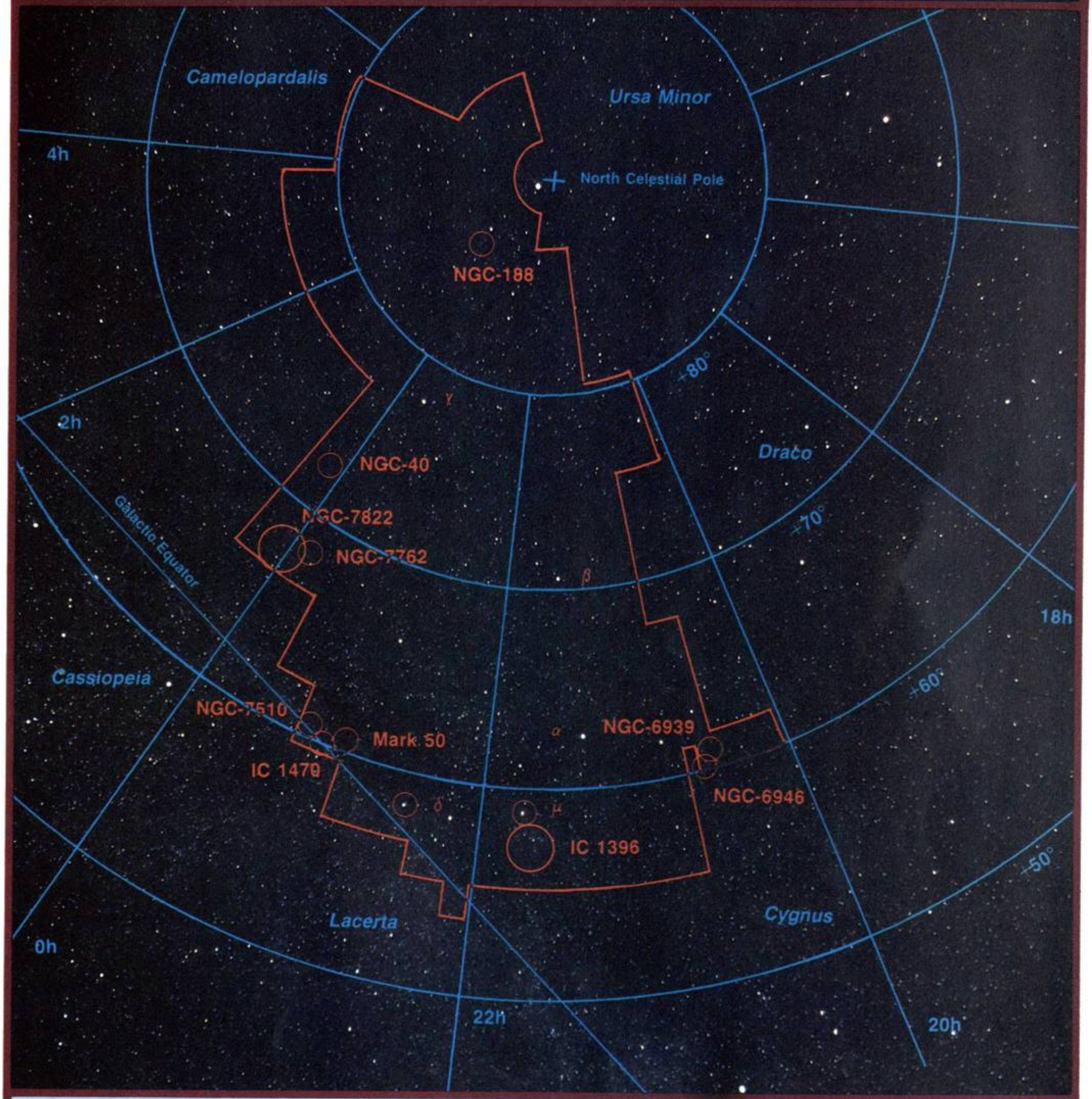


Sketches by David J. Eicher

Map by
David J. Eicher

cepheus

Photo by Robert Provin
and Brad Wallis


Camelopardalis
Ursa Minor
4h
North Celestial Pole
NGC-188
+80°
2h
γ
NGC-40
Draco
Galactic Equator
NGC-7822
NGC-7762
+70°
β
18h
Cassiopeia
+60°
NGC-7510
Mark 50
α
NGC-6939
IC 1470
δ
μ
NGC-6946
IC 1396
+50°
Lacerta
Cygnus
0h
22h
20h

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (2000)	Dec.
NGC-40	■	10.5	60″x40″	00h 10m	+72°15′	00h 13m	+72°32′
NGC-188	⊙	9.5	15′	00h 39m	+85°03′	00h 44m	+85°19′
NGC-6939	⊙	10.0	8′	20h 30m	+60°28′	20h 31m	+60°38′
NGC-6946	§	10.5	8′	20h 34m	+59°58′	20h 35m	+60°08′
IC 1396	□	14?	135′x165′	21h 38m	+57°14′	21h 39m	+57°28′
Mu	IV	3.7↔5.0	Irr	21h 42m	+58°33′	21h 44m	+58°47′
Delta	RV	3.6↔4.3	5.36d	22h 27m	+58°10′	22h 29m	+58°25′
Mark 50	⊙	8.5	?	22h 49m	+60°18′	22h 51m	+60°34′
IC 1470	■	12.5	70″x45″	23h 03m	+59°59′	23h 05m	+60°15′
NGC-7510	⊙	9.5	3′	23h 09m	+60°18′	23h 11m	+60°34′
NGC-7762	⊙	10.0	15′	23h 48m	+67°44′	23h 50m	+68°01′
NGC-7822	□	14?	220′x190′	23h 59m	+68°25′	00h 02m	+68°42′

★	*Star*
★²	*Double Star*
★³	*Triple Star*
RV	*Regular Variable*
SRV	*Semi-Regular Variable*
IV	*Irregular Variable*
EV	*Eclipsing Variable*
⊙	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
()	*Elliptical Galaxy*
§	*Spiral Galaxy*
∮	*Barred Spiral Galaxy*
#	*Peculiar/Irregular Galaxy*

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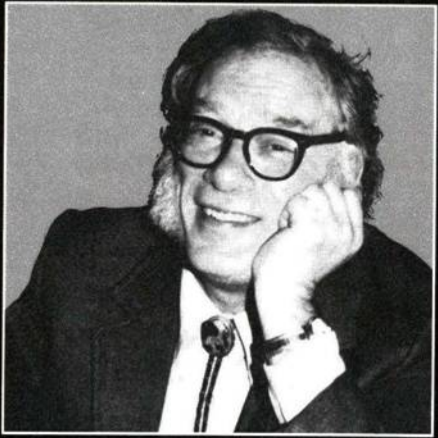

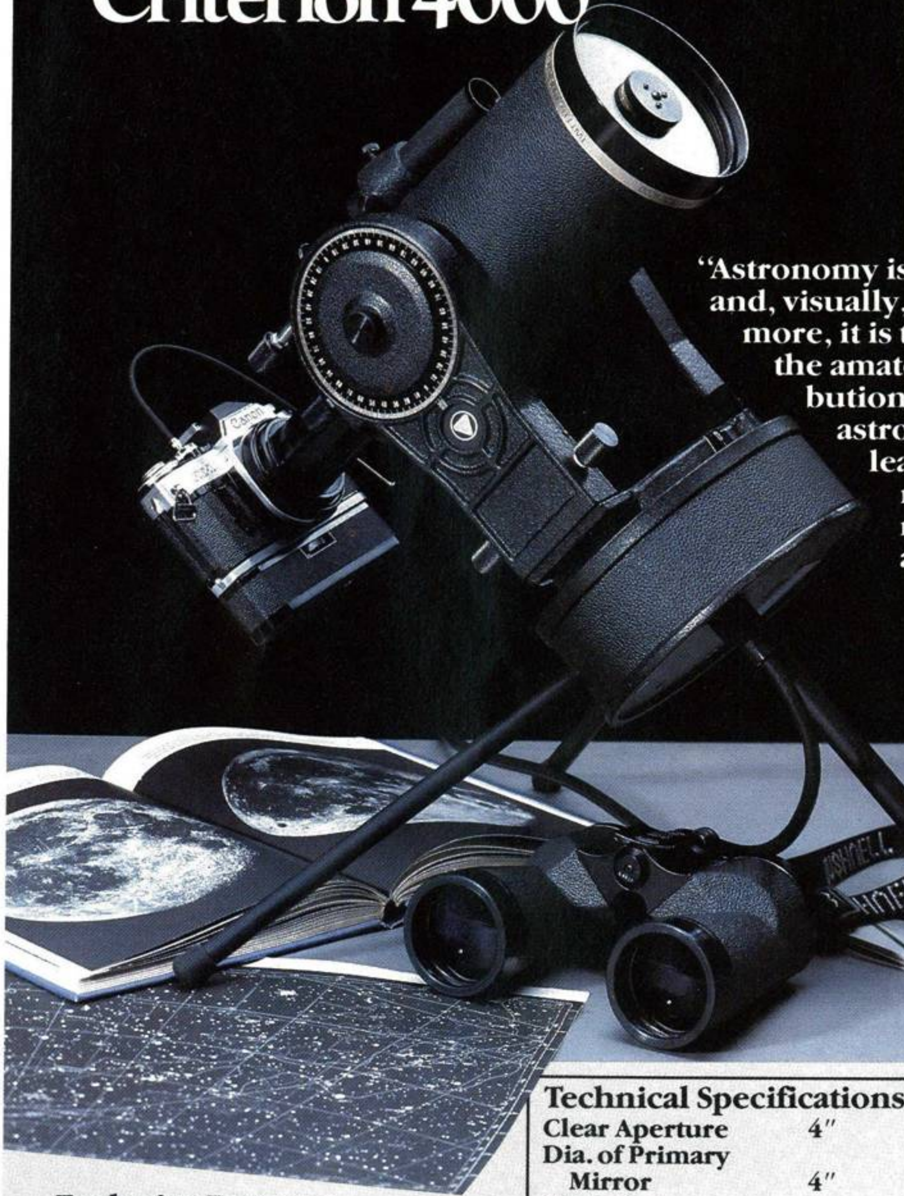

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